LMSC D-059359

(NASA-CR-170738) HIGH-SPEED MACHINING (HSM) OF SPACE SHUTTLE EXTERNAL TANK (ET) PANELS Final Report (Lockheed Missiles and Space Co.) 89 p HC A05/MF A01 CSCL 13H

N83-24727

Unclas
G3/31 03600

TASK A

FINAL REPORT

HIGH-SPEED MACHINING (HSM) OF SPACE SHUTTLE EXTERNAL TANK (ET) PANELS

25 FEBRUARY 1983

Prepared for

National Aeronautics & Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Prepared by:

Joseph A. Miller
Missile Systems Division
Lockheed Missiles and Space, Inc.
Sunnyvale, CA

Contract: NAS8-34508

FOREWARD

Lockheed Missiles and Space Company, Inc. is pleased to submit this Task A final report to the National Aeronautics and Space Administration, Marshall Space Flight Center in accordance with Contract Number NAS8-34508. The program, summarized herein, covers Task A of the contract as it has been adjusted since originally awarded. The changes made transferred the paragraph "Identify Potential High-Speed Milling Procedures" from Task A to Task B where it is entitled "High-Speed Milling Procedures and Times," and descoped the Task A paragraphs entitled "Analysis of Present Manufacturing Methods" and "Time and Motion Study."

This submission is not intended to duplicate the Task B report and documents primarily the findings of the Task A activities.

CONTENTS

CONTENTS (Cont'd)

ILLUSTRATIONS

TABLES

Section 1
INTRODUCTION

The External Fuel Tank (ET) of the Space Shuttle (Figures 1-1 and 1-2) is not recovered after launch and a new one must be provided for each launch. Currently, the external "skin" panels of the tank are produced by machining from solid wrought 2219-T87 aluminum plate stock approximately 1-3/4 inch thick. The reduction of costs in producing External Fuel Tank panels is obviously of particular significance.

This study, which is divided into Tasks A and B, was initiated to investigate the feasibility of increasing production rates and decreasing costs of the panels through the application of high-speed machining (HSM) techniques.

1-1 TASK A OBJECTIVES

Task A (the subject of this report) was designed to study potential production rates and project cost savings achieved by converting the current conventional machining process in manufacturing Shuttle External Tank panels to HSM techniques. Savings were to be projected from the comparison of current production rates with HSM rates and with rates attainable on new conventional machines. The HSM estimates were also to be based on rates attainable by retrofitting existing conventional equipment with high-speed spindle motors and rates attainable using new state-of-the-art machines designed and built for HSM.

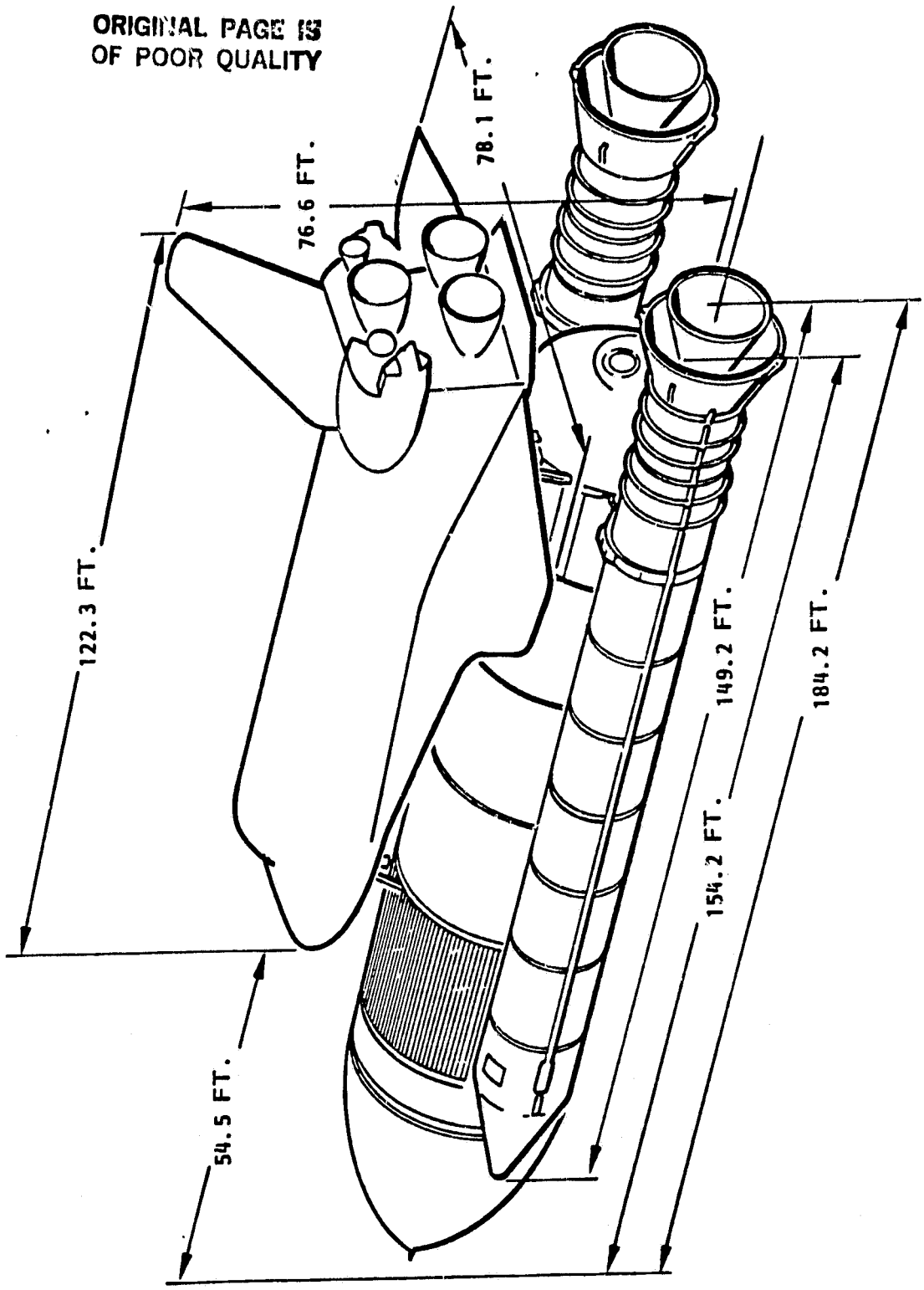


Figure 1-1. Space Shuttle Attached to External Fuel Tank

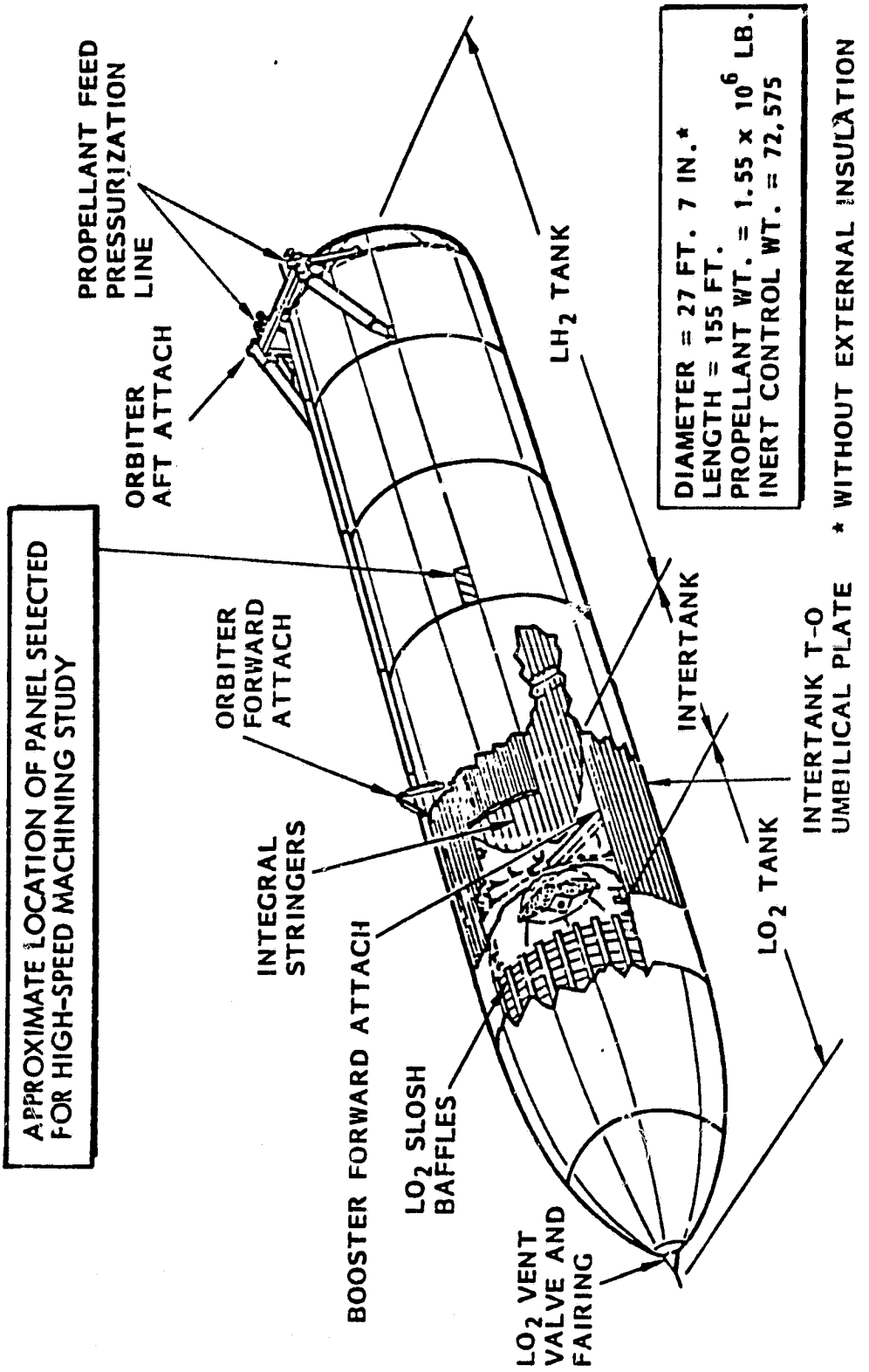


Figure 1-2. Detail of Space Shuttle External Fuel Tank

Section 2
SUMMARY - TASK A

Lockheed Missiles and Space Company, Inc., contracted with the Marshall Space Flight Center at Huntsville, Alabama to study the feasibility of transferring the high-speed machining (HSM) techniques developed at LMSC for milling aluminum missile parts to the machining of Space Shuttle External Fuel Tank Panels.

The goals of Task A were to:

a. Investigate current machining techniques.
b. Using a production rate of 64 panels per month for 84 months as a basis, compare current production rates and costs to projections based on retrofitting present equipment to HSM.
c. Compare current production rates and costs to projections based on replacing present equipment with new HSM equipment.
d. Compare current production rates and costs to projections based on replacing present equipment with new conventional equipment.
e. Perform an economic trade-off analysis comparing various machine options.

A gantry type milling machine presently being used to machine Shuttle Fuel Tank panels was utilized as a basis for comparison in this study. Information was gathered from several machine tool builders active in HSM, from HSM spindle manufacturers, and from machine tool rebuilders.

Projected machining times and labor and machine investment costs were determined for 41 specific machine tool configurations.

Findings of the study indicated that significant improvements in machining production rates and cost over the present machine used as a basis for comparison can be realized with new currently available state-of-the-art HSM equipment. Using proven HSM equipment, production rates could be increased from 3.9 panels per month currently to 73.5 panels per month. This increase in production level could be accomplished using a one panel wide, two panel long gantry-type mill with two 75 hp, 9,000 rpm spindles. The use of advanced HSM

equipment (not fully proven but at a high confidence level) with two 100 hp 12,000 rpm spindles would increase production rates to 86.6 panels per month. Projected rates for two panel wide machines are even higher, but the costs are also higher. Projected rates for unproven HSM 150 hp, 24,000 rpm spindles for both one and two panel width machines would push production rates still higher if appropriate cutters were available.

By retrofitting two 100 hp, 12,000 rpm HSM spindles on the present gantry-type mill, production rates could be increased from 3.9 panels to an estimated 43.3 panels per month. Two machines thus converted would be needed to achieve the 64 panel per month production requirement.

New conventional machines could be used to increase production rates from 3.9 currently to 87.6 panels per month. This level could be accomplished with a two panel wide, two panel long gantry-type mill and four 150 hp, 3,600 rpm spindles.

The HSM panel machining times determined from the actual 4 foot by 8 foot panel section machining performed in Task B correlated very closely with the machining times projected in Task A. As an example, 6.0 hours was projected in Task B to machine a full-size panel using a single 75 hp, 9,000 rpm spindle machine. Using the detailed procedures determined in Task A, 5.9 hours was estimated for the same situation.

Areas limiting production levels and that require further development are cutters, chip removal, and panel loading and unloading.

Section 3
TASK A EFFORT

The major efforts involved in Task A are as follows:

1) Survey present facilities.
2) Gather data on conventional machine and determine cost of conversion to HSM and projected schedule.
3) Obtain conventional machining operation steps and times.
4) Assess new machines.
5) Determine cost and delivery schedule for new conventional machine(s).
6) Determine cost and delivery schedule for HSM machines.
7) Determine barrel panel machining times for new conventional and new HSM machines.
8) Perform Economic Trade-Off Analysis comparing various machine options.
9) Produce HSM implementation plan for each option.
10) Write a final report.

4 TASK A TECHNICAL APPROACH

Following is a summarized description of the detailed steps involved in the Task A study.

4-1 SURVEY OF PRESENT FACILITIES

A visit was made to an existing machine vendor where some of the Shuttle External Tank panels are currently machined. The panel machining operation taking place on a gantry-type mill was briefly observed. Following is a compilation of the information gathered regarding the machine and the various machining parameters involved in milling the panel.

Machine: Gantry type mill (in service only 6 months since major rebuild) (Navy owned)
144" x 480" table
X axis = 480" (40')
Y axis = 144" (12')
Z axis = 12" (1')
Wilson 20 hp, 1800/3600 rpm, 440v, 3 phase spindle motor (only 13 hp available due to electrical overloading condition)
Axes motions at 240 ipm rapid and 200 ipm programmable (originally) but currently capable of 200 ipm rapid and 150 ipm programmable
All axis drives (originally hydraulic) have been replaced with dc electric drives

The gantry drive motors were:

Inland Motors
Industrial Drive Division
Radford, Virginia
Model TTF2-5306-201-B
Ser. 81D82-50
2400 rpm max.
Cont (stall) 11v, 146 amp, 60 lb-ft.
Peak (stall) 14v, 200 amp, 82 lb-ft.

Controls: Allen Bradley Model 7320 CNC

Cutter sizes and maximum cuts:

1) Roughing cutter: 5-1/4" dia, 4-flute, at 3600 rpm and 12 ipm (average of .300" deep (.475 max) at full width)
2) Finishing cutter for bottom of pocket: same as roughing cutter but only .100" deep
3) T-rib cutter: 4" dia, 6-flute, .625" or .725" flute height (full width and full depth (.725) used at 3600 rpm and 40 ipm at top of T). Maximum radial depth of cut = .575".
4) Profiling cutter for sides to T: 2-1/2" dia, at 3600 rpm and 40 ipm. (Assumed to cut 3/8" radii at bottom of T, etc.)

This information was gathered in light of possibly retrofitting the machine to HSM capabilities in addition to gaining a better understanding of how the panels are presently being machined. In regard to a possible retrofit, the new Allen Bradley Model 7320 CNC controls and the fact that the machine had been recently rebuilt were felt to be definite positive points. A point which was felt to be negative was that the maximum programmable gantry feed was rated at 200 ipm but presently the machine was limited to operation at a maximum of 150 ipm. A second negative point was that the electrical power supply to the machine appeared inadequate and would need to be remedied.

The small (20 hp) spindle motor installed on a machine originally designed for a considerably larger motor(s) indicated that problems with machine vibration may have been experienced with the larger motor(s). If so, potential problems with retrofitting to high speed spindles could be expected.

4-2 COLLECTION OF DATA FROM MACHINE TOOL BUILDERS AND REBUILDERS

To obtain pertinent information regarding state-of-the-art HSM machines and related equipment, machine tool and HSM spindle builders were contacted who were known to be actively involved in the manufacture of HSM equipment of the size and type being studied.

Information relative to new machines capable of machining the Shuttle External Tank panels at conventional machining rates was also obtained. In all instances, details were solicited regarding machine specifications, cost, and delivery schedule.

The general approach taken was to telephone the machine tool builder assuring contact with the appropriate person and then follow up by letter with the necessary details. In several instances, personal meetings were held.

One general large machine tool rebuilder was contacted regarding the possible retrofitting of the present machine to HSM capabilities. Additional retrofit information was obtained from the original manufacturer of the machine and the Bryant Grinder Division of the Excello Corporation (builder of HSM spindle motors.

4-3 SELECTION OF GENERAL MACHINE TOOL CONFIGURATIONS

The most common general approach to machining large panels such as those used for the Shuttle External Fuel Tank (11' x 20') is to mount them on a stationary horizontal table and to mount vertical (or a combination of vertical and horizontal) spindles on a moveable gantry. Considerably less moveable mass is involved in moving a gantry over the part than in moving an entire table capable of properly supporting such large parts, especially if the table is large enough to mount more than one panel at a time.

A moveable gantry type machine with one or two spindles (Figure 4-1) machining a one panel width (11') was the first general configuration considered in the study. The machine presently being used to machine Shuttle Tank panels fits into this category.

The second general configuration of machine tool included in the study was the same as the first except with a two panel length table (Figure 4-2). The lengthened table would allow loading and unloading to take place without interrupting the machining process.

A third general configuration considered was a gantry type machine capable of machining a two panel width (22'plus) using two or four spindles (Figure 4-3). This machine configuration was considered with both single and double length tables.

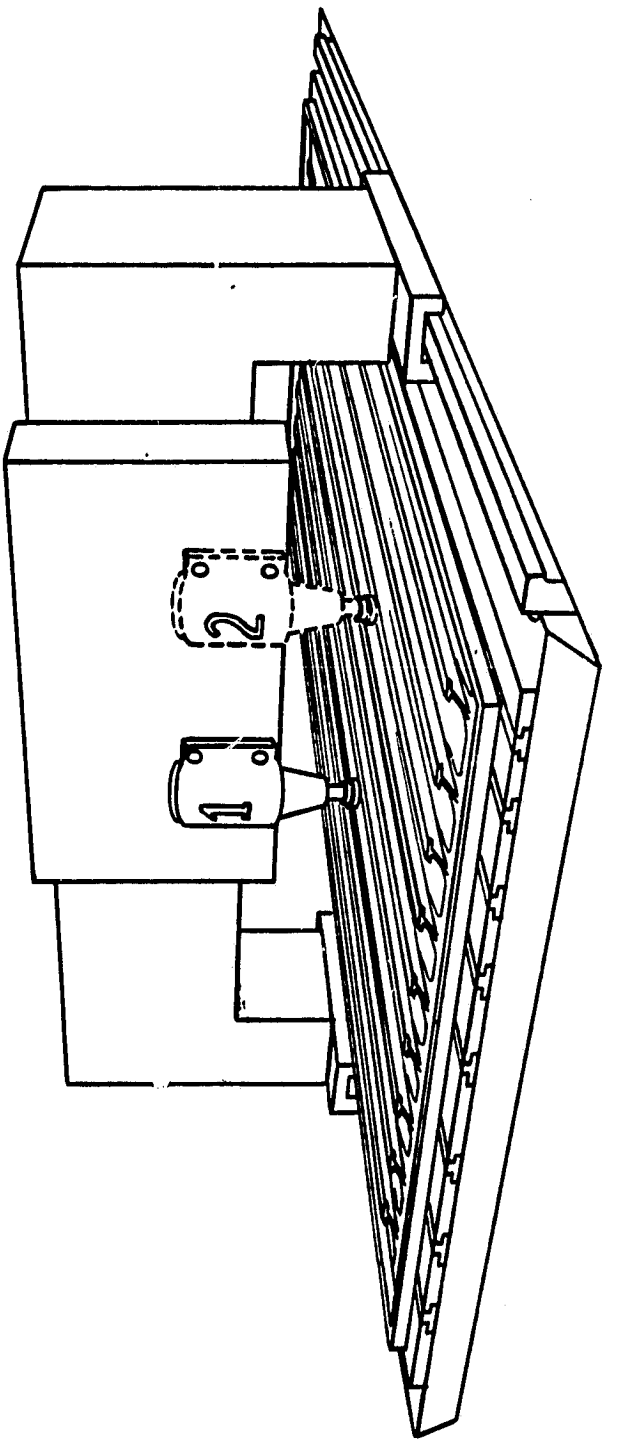


Figure 4-1. Basic Gantry-Type Machine with One or Two Spindles

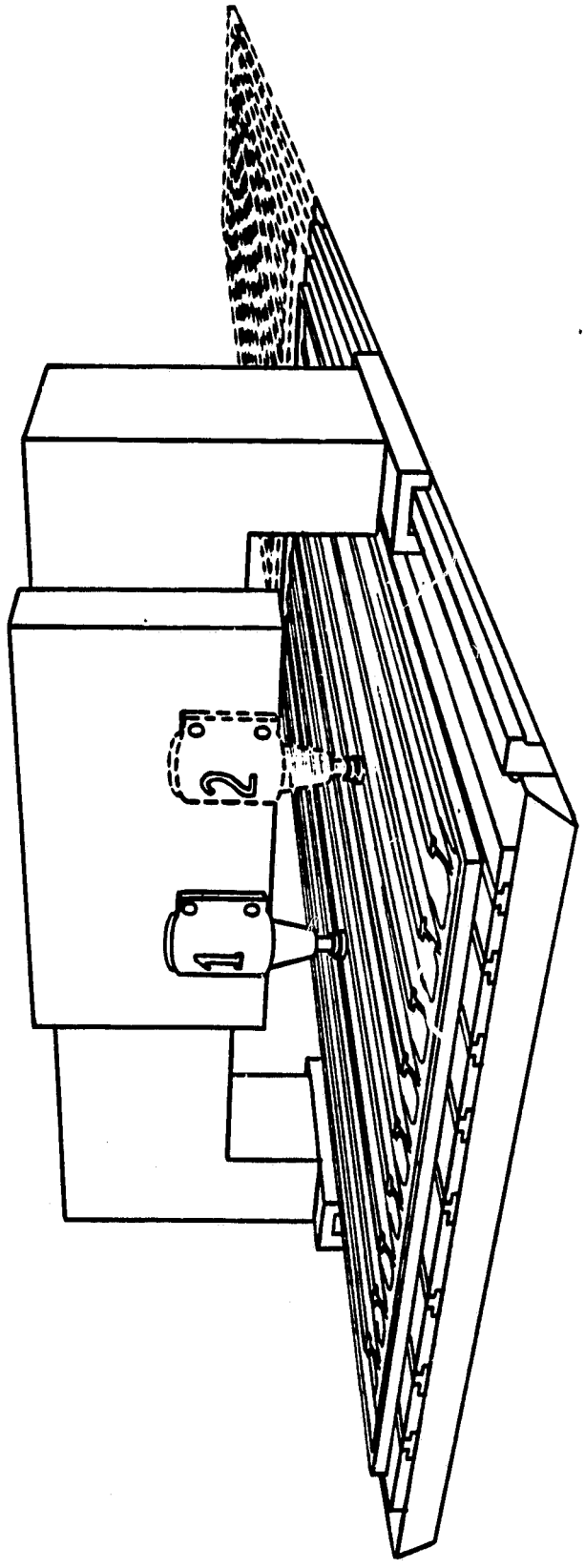


Figure 4-2. Basic Gantry-Type Machine With Lengthened Table to Allow Loading and Unloading of Second Part

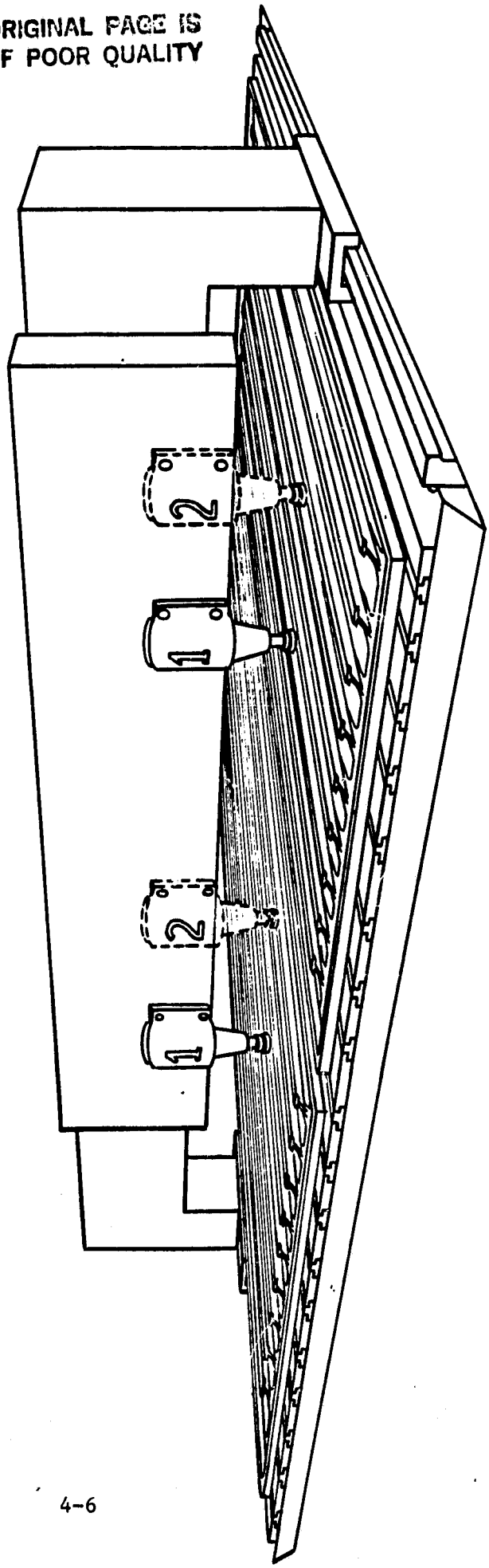


Figure 4-3. Two Panel Wide Gantry-Type Machine With Two or Four Spindles

An additional variation of the gantry type machines included in the study was a vertical spindle(s) for finish machining but separate horizontal spindle(s) for rough machining.

The fourth general configuration considered (Figures 4-4 and 4-5) involves machining panels that are mounted vertically. Either one, two, or four horizontal spindles would be used to machine one or two panels at a time. A decided advantage of mounting the panels vertically would be the relative ease of chip handling through use of a conveyor at the base of the panel.

Descriptions of the specific machine tool configurations considered in the study are included in Section 4-5.3.

4-4 DETERMINATION OF CUTTERS TO BE USED IN STUDY

The full potential of high-speed machining is still being developed. Spindles with higher rpm and horsepower are being introduced on the market. Along with these advances, however, is a definite need for more advanced cutter designs and cutter materials.

The most appropriate combinations of cutters, feeds, speeds, and depths of cut to machine the tank panels were based on the following considerations:

a) Lockheed's background in HSM
b) The cutters utilized and demonstrated in Task B of this contract
c) The cutters presently in use at the existing vendor for machining tank panels.
d) Information from sources including cutter manufacturers and machine tool builders

For the purposes of this study, a combination of both a theoretical approach (without limiting the cutting speed) and a practical approach was taken. For the theoretical approach, the assumption was made that if cutters were not yet available which could operate at the desired cutting speeds (sfpm), technology would soon develop and provide them. For the practical approach basically the same general cutter specifications (diameter and number of teeth) as are presently being used were assumed for most of the machining operations. The assumption was also made that proper adjustments in cutter

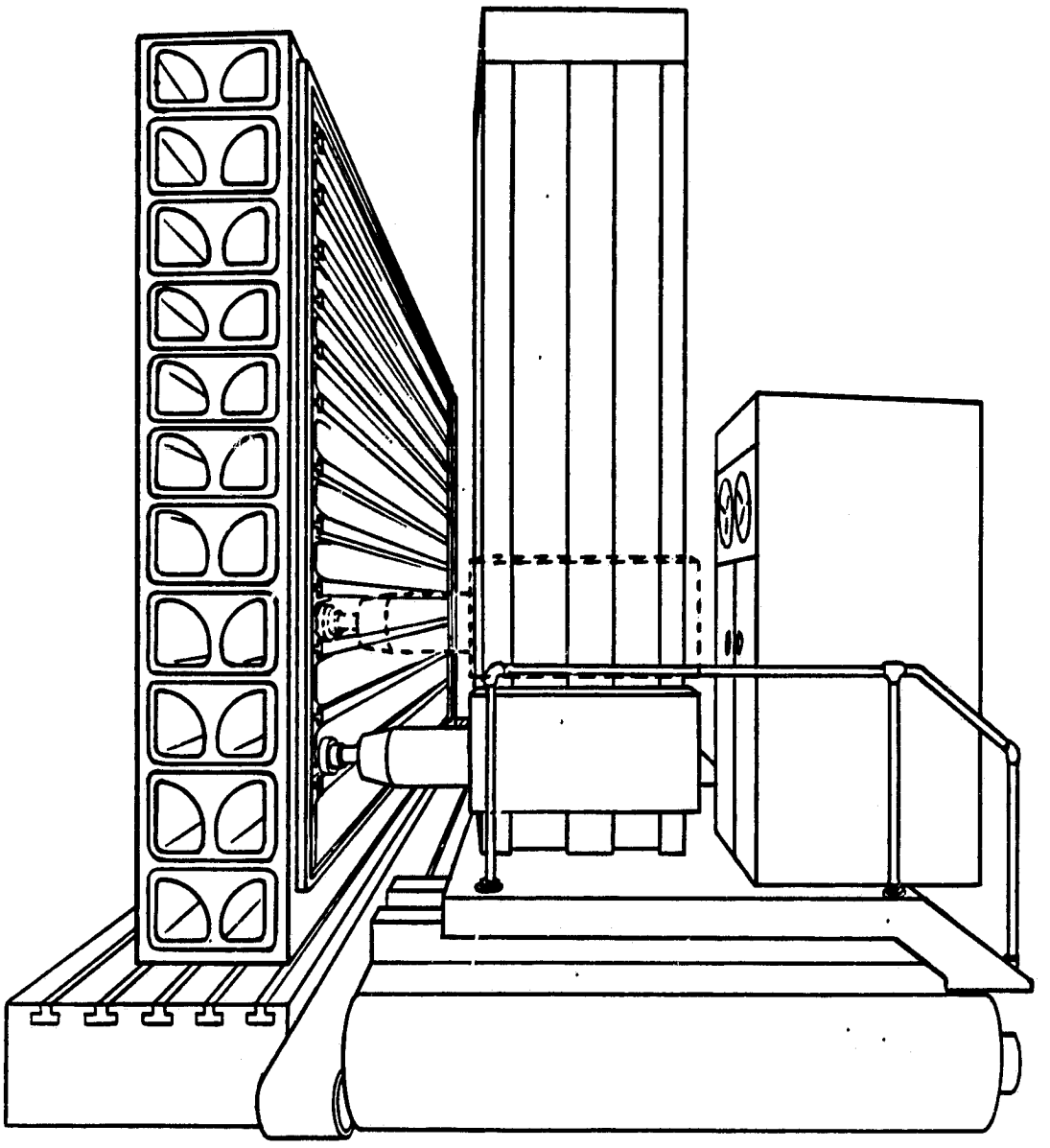


Figure 4-4. Moveable Column Machine With One or Two Spindles

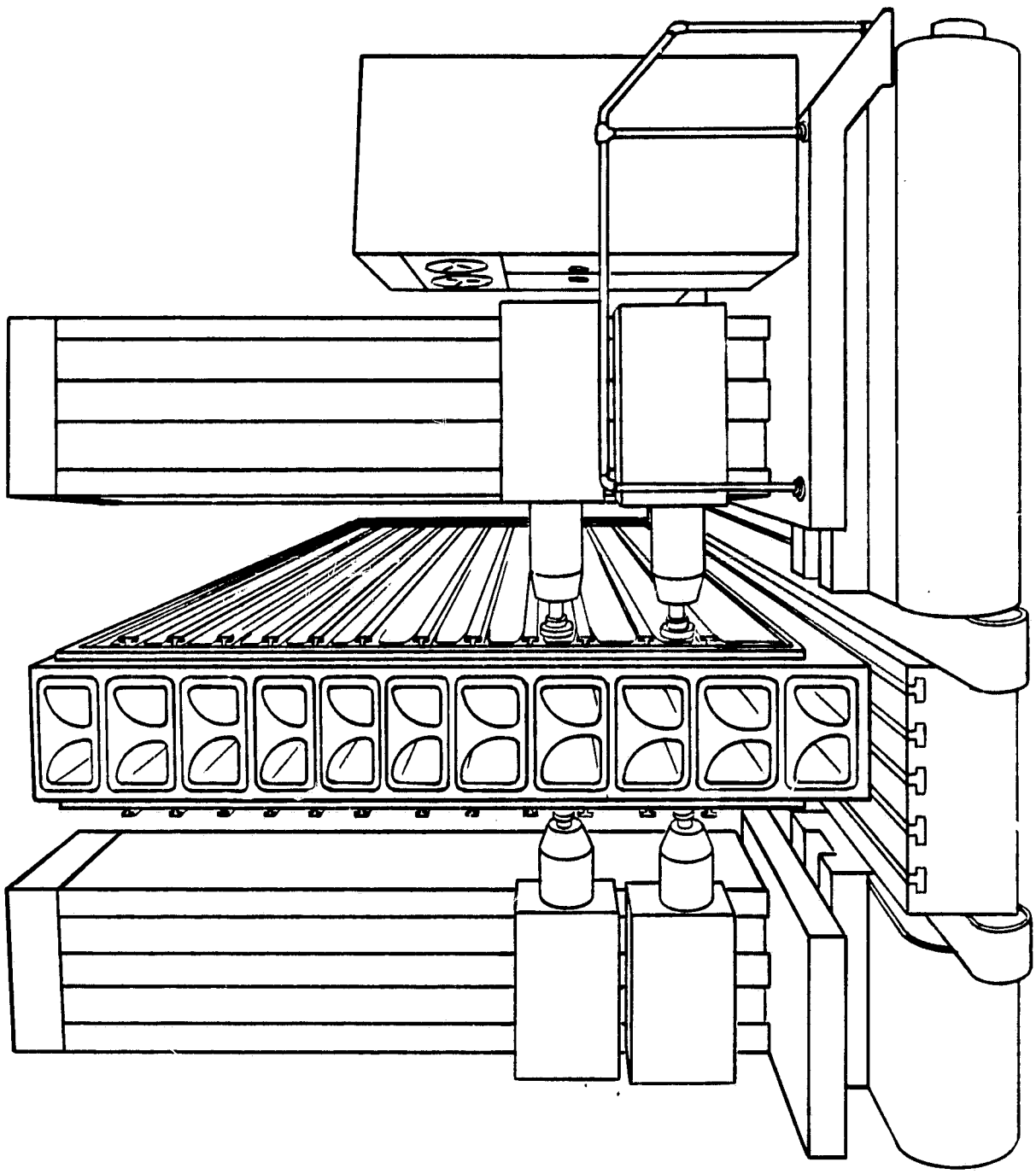


Figure 4-5. Double Moveable Column Machine With Four Spindles

angles and other details would be made to correlate with the higher cutting speeds projected in the study. However, for roughing and finishing the pockets between the T-ribs of the panels, calculations for different cutter diameters were examined (See Section 5 and Appendixes A and B for details).

Substitutions for the 5-1/4 inch diameter-four toothed cutter presently in use for both roughing and finishing included 1) a 14 inch diameter by 2.8 inch wide roughing cutter to be used with the horizontal spindle motors; 2) a 2 inch diameter, three-flute end mill for roughing, and 3) a 9 inch diameter cutter for roughing and finishing. The 9 inch cutter would have the advantage of finishing the entire width of the pocket in one pass thus eliminating tool marks and potential mismatch in the bottom of the pocket.

Except for the very highest theoretical cutting speeds, the cutters and accompanying parameters chosen were considered reasonable, but not necessarily optimum. For example, more teeth for a given diameter might improve machining time if ample chip clearance for the higher cutting speeds could still be provided.

Safety, especially at the higher cutting speeds, is an obvious concern regarding any cutter development and usage. Brazed carbide insert-type cutters were assumed for instances where insertable teeth might not be safe.

4-5 CALCULATIONS OF MACHINING TIMES AND PRODUCTION CAPACITIES

A required production rate of 64 Shuttle External Tank panels per month for 84 months starting in 1985 was specified by NASA as a basis for this study. The specific objectives of the study were to determine potential production rates and cost savings from converting to HSM techniques from the conventional machining process presently employed in milling the panels from 1.75 inch thick aluminum plate.

A consideration of all aspects of the panel production process was not within the scope of this study. The results shown are intended for comparison with only the appropriate portions of the total process. Estimated machining rates for these portions of the present process are included. Examples of machining operations not included in the comparisons are the preparation of the outside or bottom of the panels and the drilling and tapping of holes. Both of these operations can be considered to take place on other equipment and are not considered necessary to the study.

The following sub-sections describe the considerations involved in projecting machining times and production capacities for the general machine tool configurations described previously in Section 4-3.

4-5.1 Selection of Typical Panel

The panel specified for this study by the NASA Marshall Space Flight Center and their prime contractor for the Shuttle Tank, Martin Marietta, was described on Martin Marietta Drawing Number 8094200997. This panel is comparable to the one from which the demonstration sample was machined as part of Task B. It is 11 feet wide by 20 feet long and is milled from 1.75 inch thick 2219-T87 aluminum plate. Twelve longitudinal T-shaped reinforcing ribs are spaced 10.8 inches apart (Figure 4-6). An estimated 91 percent of the metal is removed.

The panel is machined from a premachined blank from which over half of the metal has already been removed. However, for the purposes of this study, all machining times including the references, are based on starting from a 1.75 inch thick solid plate.

4-5.2 Cutting Speed Limitations

As a basis for the study, projected machining rates and panel production capacities were calculated without the restraints of cutting speed limitations (expressed in surface feet per minute-sfpm). Essentially, the assumption was made that cutters were available (or would soon become available) that would allow the utilization of the full capacities of the machine tools. The tables shown in this report are based upon this assumption.

In several instances, the cutting speeds calculated were substantially above current demonstrated levels. Upon investigation, a smaller diameter cutter at the same rpm but deeper axial depth of cut was found to remove a similar amount of metal at a lower cutting speed (in currently proven range). For example, the 2 inch, 3-flute end mill used in the 150 hp, 24,000 rpm spindle machines as a roughing cutter with a .508 inch depth of cut provided similar metal removal rates as the 9 inch cutter with a .066 inch depth of cut on the same machines (Table A-1, Appendix A).

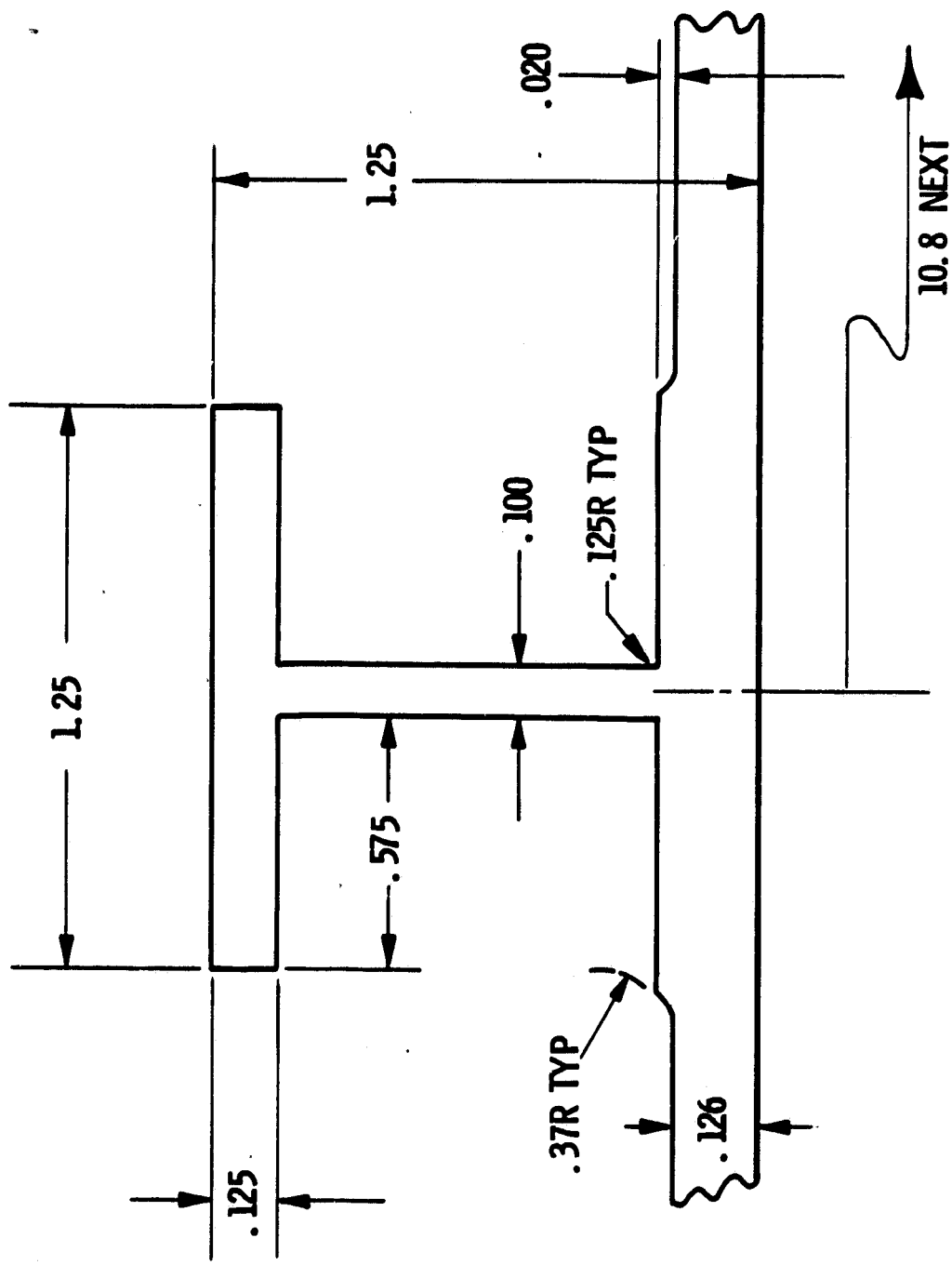


Figure 4-6. Section View of T-Rib Reinforcement of Fuel Tank Panel

The potential for obtaining cutters capable of the maximum cutting speed indicated in this study (56,549 sfpm) was pursued further. A spokesman for a major cutter manufacturer involved directly in cutter development for HSM stated that a cutter capable of machining aluminum at 56,000 sfpm is felt to be feasible. Cutting speeds in aluminum at up to at least 28,000 sfpm have already been demonstrated successfully.

4-5.3 Specific Machine Tool Configurations Used in Study

Projected panel machining times and monthly production rates were determined for the following specific gantry type machine tool configurations. (The columns of the tables showing the results are arranged in this order throughout the report):

a) Present conventional gantry type mill with one 20 hp, 3,600 rpm spindle, and 200 ipm gantry feed (Figure 4-1).

b) Present conventional gantry type mill retrofitted with new HSM 100 hp, 2,600 rpm conventional spindle(s) (1 or 2) and 200 ipm gantry feed (Figure 4-1).

c) Present conventional gantry type mill retrofitted with new HSM 100 hp, 12,000 rpm spindle(s) (1 or 2) and 200 ipm gantry feed (Figure 4-1).

d) New Conventional gantry type mill with horizontal 100 hp, 3,600 rpm and vertical 150 hp, 3,600 rpm spindle combination(s) (2, 4 or 8 spindles) and 300 ipm gantry feed for one panel width and 200 ipm gantry feed for two panel widths (This configuration is similar to Figures 4-1 and 4-3 but with both vertical and horizontal spindles).

e) New conventional gantry type mill with vertical 150 hp, 3,600 rpm spindle (s) (1, 2 or 4) and 300 ipm gantry feed for one panel width and 200 ipm gantry feed for two panel width (Figures 4-1 and 4-3).

f) New HSM gantry type mill with vertical 75 hp, 9,000 rpm spindle(s) (1, 2, or 4) and 600 ipm gantry feed for one panel width and 200 ipm for two panel widths (Figures 4-1 and 4-3).

g) New HSM gantry type mill with vertical 100 hp, 12,000 rpm spindle(s) (1, 2, or 4) and 400 ipm gantry feed for one panel width and 200 ipm for two panel widths (Figures 4-1 and 403).

h) New HSM gantry type mill with vertical 150 hp, 24,000 rpm spindle(s) (1, 2 or 4) and 1,000 ipm gantry feed for both one and two panel widths (Figures 4-1 and 403).

i) New HSM gantry type mill (same as 8) except calculations are made using different roughing cutter.

Machining times and production rates were also calculated for configurations d) thru h) with two panel length tables. The lengthened tables were to provide loading and unloading capability without interrupting the machining process.

The outputs from the vertical panel machines (Figures 4-4 and 4-5) are expected to be comparable to the outputs attainable on the horizontal panel machines. However, development of the vertical panel machines has not progressed as far as for the horizontal machines and a column feed rate of 200 ipm was the apparent maximum.

4-5.4 Machining Parameters (Appendixes A and B)

Cutters

The study was based primarily on cutter sizes used for the present operation. where applicable (Section 4-1 and 4-4). The cutters used for roughing and finishing the pockets between the T-ribs were changed from the 5-1/4 inch diameter to 9 inches in most instances. For the combination horizontal and vertical spindle machines, a 14 inch diameter by 2.7 inch wide staggered tooth cutter with 8 teeth was used for roughing. This cutter was reportedly being used effectively on similar panels being machined at other facilities A 9 inch diameter cutter in the vertical spindle was used for the finishing.

Calculations were also made for roughing and finishing the pockets using a 5-1/4 inch cutter (as now used) on all of the machine configurations. The results are not shown in the report since in all instances the time was greater than when using the 9 inch diameter cutter.

Spindle Speeds

The maximum rpm available was used unless otherwise noted.

Horsepower Required

The metal removal rates are based on a full 100 percent of the rated horsepower of the spindle motors. The amount shown was calculated by dividing the cu in./min by a cutting efficiency factor of 4.0 cu in./min/hp (demonstrated in Task B and in other instances of HSM).

Chip Load

HSM research has defined optimum chip loads (chip per tooth) for milling aluminum[1]. Chip loads of .007 inches for roughing and .003 inches for finishing were taken from these recommended ranges and maintained as constants throughout the study. Exceptions were the present operations and a few other instances as noted where machine capabilities were limiting.

Number of Layers

The number of layers in which the metal in the pockets between the ribs was rough machined was determined by computing the maximum cross-sectional area of metal removeable based upon a cutting efficiency factor of 4.0 cu in/min/hp and the available horsepower. The maximum axial depth of cut equivalent for the full diameter (radial depth of cut) of the cutter was then calculated. This maximum depth per pass was then divided into the total roughing depth of 1.525 inches (1.75"-.100" finish cut - .125" panel thickness). The figure was adjusted to the next larger whole number and the 1.525 inch roughing depth was divided into equal depth layers each of which was considered to be the depth of cut (axial).

Number of Passes per Pocket

The number of passes per pocket was determined by multiplying the number of layers by the number of passes per layer.

Depth of Cut (Axial)

(See Number of Layers)

Depth of Cut (Radial)

The full diameter of the cutter was used as the radial depth of cut for the vertical spindles. For the horizontal spindles the radial depth was calculated depending on the number of passes required to achieve the depth of the pocket.

Table (Gantry) Feed Used

This value was calculated in each instance based on constant chip load, rpm, and number of teeth in the cutter. The calculated value was used unless the maximum capability of the machine was limiting. In such instances the exception was noted.

Cu In./Min - Metal Removal Rate

The metal removal rate value in cubic inches per minute was based on the maximum rate used and the full width of the cutter.

---

[1]J. McGee et al, "Manufacturing Methods for High Speed Machining of Aluminum," Final Technical Report, Vought Corporation contract No. DAAK-40-76-C-1329; submitted to U. S. Army Missile Research and Development Command, February 1, 1978.

Cutting Speed

This value was computed as the peripheral speed of the cutter at the given rpm expressed in surface feet per minute (sfpm).

4-5.5 Chip Cutting Time for Each Machining Operation

Chip cutting time was considered to be only that time during which the revolving cutter is actually engaging the workpiece. Detailed calculations for each of the separate machining operations and for each machine configuration considered are shown in Appendixes A and B. The cutter paths used are considered reasonable but not necessarily optimum. Optimization of the cutters and other parameters should yield even shorter cutting times. A summary of these individual machining operation times and a composite total is provided in Table 4-1.

The data (Table 4-1) show that as rpm is increased the total chip cutting time is decreased. Theoretically, if a table feed of 1,344 ipm had been available for the 150 hp, 24,000 rpm spindle machine, an additional .359 hours (21.54 minutes) per panel would have been saved.

The values shown in Table 4-1 (and Appendixes A and B) are based upon one spindle operation. These one spindle values are expanded to the two and four spindle levels by dividing the one spindle chip cutting time by two and by four, respectively.

4-5.6 Total Machining Time

Machining time was computed to be the sum of chip cutting time plus between pass cutter positioning time. The time allowed for positioning was adjusted according to the maximum gantry feed available for the particular machine tool configuration. Tool changes, operator break, and down times were not included.

Table 4-2 shows the estimated machining time per spindle for one, two, and four spindle machines. This separation was required because the gantry feed of the four spindle machines is slower.

Table 4-1. Summary of Estimated Chip Cutting Time (Hours), Per Panel (Based on One Spindle)

	MACHINE TOOL CONFIGURATIONS								
	RETROFIT		NEW						
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
MACHINING OPERATIONS									
Mill Top of T's	4.032	.547	.239*	.547	.547	.225	.167	.084	.084
Rough Mill Pockets	32.256	1.813	1.813*	2.766	1.295	2.368	1.716	1.220**	1.426
Finish Mill Pockets (.100")	8.064	.593	.259*	.593	.593	.243	.181	.084	.084
Mill T-Ribs	4.838	4.493	1.382	4.493	4.493	1.728	1.382	.691	.691
Mill Edge of T's and Radii	2.419	2.246	.691	2.246	2.246	.864	.691	.346	.346
Mill Taper on T Ends	.040	.040	.040	.040	.040	.040	.040	.040	.040
Mill Periphery	.256	.238	.073	.238	.238	.092	.073	.037	.037
Total Chip Cutting Time	51.905	9.970	4.497*	10.923	9.452	5.560	4.250	2.502**	2.708

*Limited by 200 ipm table travel.
**Limited by 1000 ipm table travel.

Table 4-2. Summary of Estimated Machining Time Per Panel
(Chip Cutting Time Plus Cutter Positioning Time)

	MACHINE TOOL CONFIGURATIONS								
		RETROFIT		NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING (HSM)			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Total Chip Cutting Time (Hours)	51.905	9.970	4.497	10.923	9.452	5.560	4.250 (4.497 for 4 Spindles)	2.502	2.708
Positioning Time Per Pass									
- One or Two Spindle Machine (Hours)	.0025	.0025	.0025	.00167	.00167	.00083	.00125	.0005	.0005
- Four Spindle Machine (Hours)	-	-	-	.0025	.0025	.0025	.0025	.0005	.0005
# of Passes	225	209	209	266	183	417	404 (209)	416	303
Total Cutter Positioning Time									
-One or Two Spindle Machine (Hours)	.563	.523	.523	.444	.306	.346	.505	.208	.152
-Four Spindle Machine (Hours)	-	-	-	.665	.458	1.043	.523	.208	.152
Total Machining Time (Hours)									
-One or Two Spindle Machine (Hours)	52.468	10.493	5.020	11.367	9.758	5.906	4.755	2.710	2.860
-Four Spindle Machine (Hours)	-	-	-	11.588	9.910	6.603	5.020	2.710	2.860

4-5.7 Total Floor-to-Floor Machining Time and Monthly Panel Machining Capacity
Total floor-to-floor time was determined to be the machining time plus operator break, fatigue, and personal time plus panel loading and unloading time. The operator break, fatigue, and personal time was estimated at 20 percent of machining time. Panel loading and unloading time was included at the reported present rate of 3.0 hours for the one panel width machines and an estimated 4.5 hours (2.25 hours per panel) for the two panel width machines. As the loading and unloading times were considered to be different for one and two panel width machines and also for one and two panel length machines, separate tables (C-1 through C-6) are shown in Appendix C for each of these categories. The monthly panel machining capacity was computed by dividing the total floor-to-floor time into the 325.5 hours per month total production time available on a two shift basis. This 325.5 hours per month was determined as follows:

Day shift:	21 days x 8 hours/day	=	168 hours
Swing shift:	21 days x 7.5 hours/day	=	157.5 hours
	Total for two shifts	=	325.5 hours

Operator break, fatigue, and personal time have already been included in the floor-to-floor time. However, maintenance and other down times have not been allowed for.

A summary of total floor-to-floor machining time and monthly panel machining capacity is given in Tables 4-3 and 4-4.

It is noteable that in all instances the estimated monthly panel capacity increases as rpm is increased unless the capacity is limited by the load and unload time. It is also of interest that the estimated monthly panel capacity increases for each number of spindles when the table is lengthened to allow loading and unloading during machining.

4-6 ECONOMIC TRADE-OFF ANALYSIS

An economic trade-off analysis is a very important aspect of the High-Speed Machining of Space Shuttle External Tank Panels study. Even though the HSM process might be shown to produce panels faster, if the cost for producing the panels by this means is too high the change could not be justified. The approach taken to determine the estimated costs involved in machining panels using each of the 41 machine tool configurations included in the study was to assess both the machine investment cost and the machining time or labor figure. Some additional manufacturing costs, such as panel premachining which were considered to be essentially the same for each of the configurations, were not included in

Table 4-3. Summary of Total Floor-to-Floor Machining Time, Per Panel, and Monthly Panel Machining Capacity

One Panel Length Machine

	MACHINE TOOL CONFIGURATIONS								
	PRESENT	RETROFIT		NEW					
		CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING (HSM)			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
One Spindle									
Total Floor-to-Floor Time (Hours)	65.962	15.592	9.024	16.640	14.710	10.087	8.706	6.252	6.432
Monthly Capacity									
2 shifts/80% Cap.	3.9	16.7	28.9	15.6	17.7	25.8	29.9	41.7	40.5
2 shifts/100% cap.	4.9	19.5	36.1	19.6	22.1	32.3	37.4	52.1	50.6
Two Spindle									
Total Floor-to-Floor Time (Hours)	-	9.296	6.012	9.821	8.855	6.544	5.854	4.626	4.716
Monthly Capacity									
2 shifts/80% Eff.	-	28.0	43.4	26.5	29.4	39.8	44.5	56.3	55.2
2 shifts/100% Eff.	-	35.0	54.1	33.1	36.8	49.7	55.6	70.4	69.0
Four Spindle									
Total Floor-to-Floor Time (Hours)	-	-	-	5.726	5.224	4.196	3.743	3.064	3.108
Monthly Capacity									
2 shifts/80% Eff.	-	-	-	45.5	49.8	62.1	69.6	85.0	83.8
2 shifts/100% Eff.	-	-	-	56.8	62.3	77.6	87.0	106.2	104.7

Table 4-4. Summary of Total Floor-to-Floor Machining Time, Per Panel, and Monthly Panel Machining Capacity

Two Panel Length Machine

(XXX) value if not limited by equipment	MACHINE TOOL CONFIGURATIONS								
		RETROFIT		NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING (HSM)			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
One Spindle									
Total Floor-to-Floor Time (Hours)	65.962	-	-	13.640	11.710	7.087	5.706	3.252	3.432
Monthly Capacity									
2 shifts/80% Eff.	3.9	-	-	19.1	22.2	36.7	45.6	80.1	75.9
2 shifts/100% Eff.	4.9	-	-	23.9	27.8	45.9	57.0	100.1	94.8
Two Spindle									
Total Floor-to-Floor Time (Hours)	-	-	-	6.821	5.855	3.544 (2.854)	3.000 (2.854)	3.000 (1.626)	3.000 (1.716)
Monthly Capacity									
2 shifts/80% Eff.	-	-	-	38.2	44.5	73.5	86.8 (91.2)	86.6 (160.1)	86.8 (151.7)
2 shifts/100% Eff.	-	-	-	47.7	55.6	91.8	108.5 (114.1)	108.5 (200.2)	108.5 (189.7)
Four Spindles									
Total Floor-to-Floor Time (Hours)	-	-	-	3.476	2.974	2.250 (1.946)	2.250 (1.493)	2.250 (.814)	2.250 (.858)
Monthly Capacity									
2 shifts/80% Eff.	-	-	-	74.9	87.6	115.7 (133.8)	115.7 (174.4)	115.7 (319.9)	115.7 (303.5)
2 shifts/100% Eff.	-	-	-	93.6	109.4	144.7 (167.3)	144.7 (218.0)	144.7 (399.9)	144.7 (379.4)

the comparison study.

The production requirements were specified to be 64 panels per month for 84 months (5,376 panels) starting in 1985. The costs were computed both per panel and per the total 5,376 panels.

4-6.1 Labor Costs Per Panel and Per 5,376 Panels

The labor cost per panel for each of the 41 configurations was determined by multiplying the total floor-to-floor machining time per panel by a constant labor rate. An appropriate labor charge for the type of work and equipment involved was estimated at $60 per hour. These labor costs are shown in Table D-1 and D-2 of Appendix D. Also shown are the labor costs projected for the total 5,376 panels if machined by each of the configurations.

4-6.2 Machine Investment Costs Per Panel and Per 5,376 Panels

The costs of the machines were estimated by various machine tool builders. A degree of interpolation was involved in costing certain specific machine tool configurations. In the case of the retrofit machines, no value for the present machine was allowed; only additional investment costs were figured. The primary costs for the retrofits were for the HSM spindle motor systems.

The cost of the vacuum chuck system was, in some instances, included in the cost of the machine. The estimates for installation and debug and test were determined from inputs from the machine tool builders and from Lockheed personnel experienced in the area (Tables E-1 through E-6, Appendix E).

4-6.3 Combined Machine Investment Plus Labor Costs Per Panel and Per 5,376 Panels

The machine investment costs and the labor costs for the various machine tool configurations are combined in Tables F-1 through F-6 of Appendix F. Both costs per panel and per the total of 5,376 panels are shown. Summary comparisons of these combined costs per panel are given in Table 4-5 and total costs for all 5,376 panels are given in Table 4-6.

Of interest is the indication that, for the new machines, the combined cost per panel goes down as the rpm of the spindle motors goes up.

Table 4-5. Summary of Combined Total Machine Investment Plus Labor Cost ($) Per Panel

(XXX) values not limited by load/unload times	MACHINE TOOL CONFIGURATIONS								
	PRESENT	RETROFIT		NEW					
		CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
One Spindle									
One Panel Length Table	3,958	945	586	1,409	1,266	923	859	651	662
Two Panel Length Table	-	-	-	1,310	1,167	1,972	741	501	512
Two Spindle									
One Panel Length Table	-	577	437	1,056	942	739	753	879	606
Two Panel Length Table	-	-	-	957	844	622	645 (636)	533 (451)	535 (456)
Four Spindle									
One Panel Length Table	-	-	-	1,013	852	791	783	667	669
Two Panel Length	-	-	-	991	830	787 (769)	806 (761)	676 (590)	676 (592)

Table 4-6. Summary of Combined Total Machine Investment Plus Labor Cost ($) Per 5,376 Panels

(XXX) values not limited by load/ unload times

	MACHINE TOOL CONFIGURATIONS								
	PRESENT	RETROFIT		NEW					
		CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING (HSM)			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
One Spindle									
One Panel Length Table	21,278K	5,082K	3,150K	7,575K	6,807K	4,962K	4,616K	3,501K	3,560K
Two Panel Length Table	-	-	-	7,043K	6,274K	4,330K	3,984K	2,693K	2,752K
Two Spindle									
One Panel Length Table	-	3,102K	2,352K	5,677K	5,066K	3,974K	4,048K	3,231K	3,257K
Two Panel Length Table	-	-	-	5,147K	4,535K	3,343K	3,466K (3,417K)	2,866K (2,425K)	2,866K (2,452K)
Four Spindle									
One Panel Length Table	-	-	-	5,448K	4,582K	4,252K	4,208K	3,588K	3,599K
Two Panel Length Table	-	-	-	5,331K	4,464K	4,233K (4,136K)	4,333K (4,019K)	3,633K (3,170K)	3,633K (3,181K)

4-6.4 Comparison of Monthly Panel Machining Capacities of Various Machine Tool Configurations

Table 4-7 shows the projected monthly panel machining capacities of the 41 different machine tool configurations. Details are compiled in Appendix C. The information in Table 4-7 is based on a 100 percent efficiency factor after operator break, fatigue, and personal time have been allowed.

Additional time should be allocated for maintenance (commonly 10 percent or higher for conventional numerical control machining centers) and other miscellaneous reasons. Furthermore, in this study no time has been allowed for secondary machining operations such as drilling and tapping holes while the part is still mounted on the machine. A realistic estimate of actual productive machine time for the milling operation would be 80 percent. Table 4-8 shows the projected monthly panel machining capacities of the 41 machine tool configurations at this 80 percent level.

4-6.5 Selection of Best Alternative Machine Configurations

Criteria used for selection were:

a) The machine must meet or exceed the production requirement of 64 panels per month (using the 80 percent efficiency level).

b) The panels must be produced at the least reasonable combined total machine investment plus labor cost.

c) The machine tool configuration must be reasonably well proven.

Table 4-9 shows the 15 machine tool configurations selected which are expected to meet or surpass the 64 panel per month production requirement. In addition to the monthly panel capacity, the combined total machine investment and labor costs are shown. Eight of the 15 configurations involve the 150 hp, 24,000 rpm spindle which at this time is felt to need further proofing before it can be recommended. Table 4-10 shows the machine tool configurations selected for each of the three following major categories.

a) Retrofit HSM

Two present gantry type milling machines (each retrofitted with two 100 hp, 12,000 rpm vertical spindles) show a combined projected panel machining capacity of 86.6 panels per month at an estimated labor plus additional investment cost for the retrofit of $4,704,000 or $875 per panel.

Table 4-7. Estimated Panel Machining Capacities of 41 Machine Tool Configurations -Panels/Month

100 Percent Efficiency Level

(XXX) values not limited by load/ unload times

	MACHINE TOOL CONFIGURATIONS								
	RETROFIT		NEW						
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING (HSM)			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
One Spindle									
One Panel Length Table	4.9	19.5	36.1	19.6	22.1	32.3	37.4	52.1	50.6
Two Panel Length Table	-	-	-	23.9	27.8	45.9	57.0	100.1	94.8
Two Spindle									
One Panel Length Table	-	35.0	54.1	33.1	36.8	49.7	55.6	70.4	69.0
Two Panel Length Table	-	-	-	47.7	55.6	91.8	108.5 (114.1)	108.5 (200.2)	108.5 (189.7)
Four Spindle									
One Panel Length Table	-	-	-	56.8	62.3	77.6	87.0	106.2	104.7
Two Panel Length Table	-	-	-	93.6	109.4	144.7 (167.3)	144.7 (218.0)	144.7 (399.9)	144.7 (379.4)

Table 4-8. Estimated Monthly Panel Machining Capacities of 41 Machine Tool Configurations (Number of Panels)

(Two Shift Operation)
80 Percent Efficiency Level

(XXX) values not limited by load/unload times

*(XXX) values not limited by gantry speed

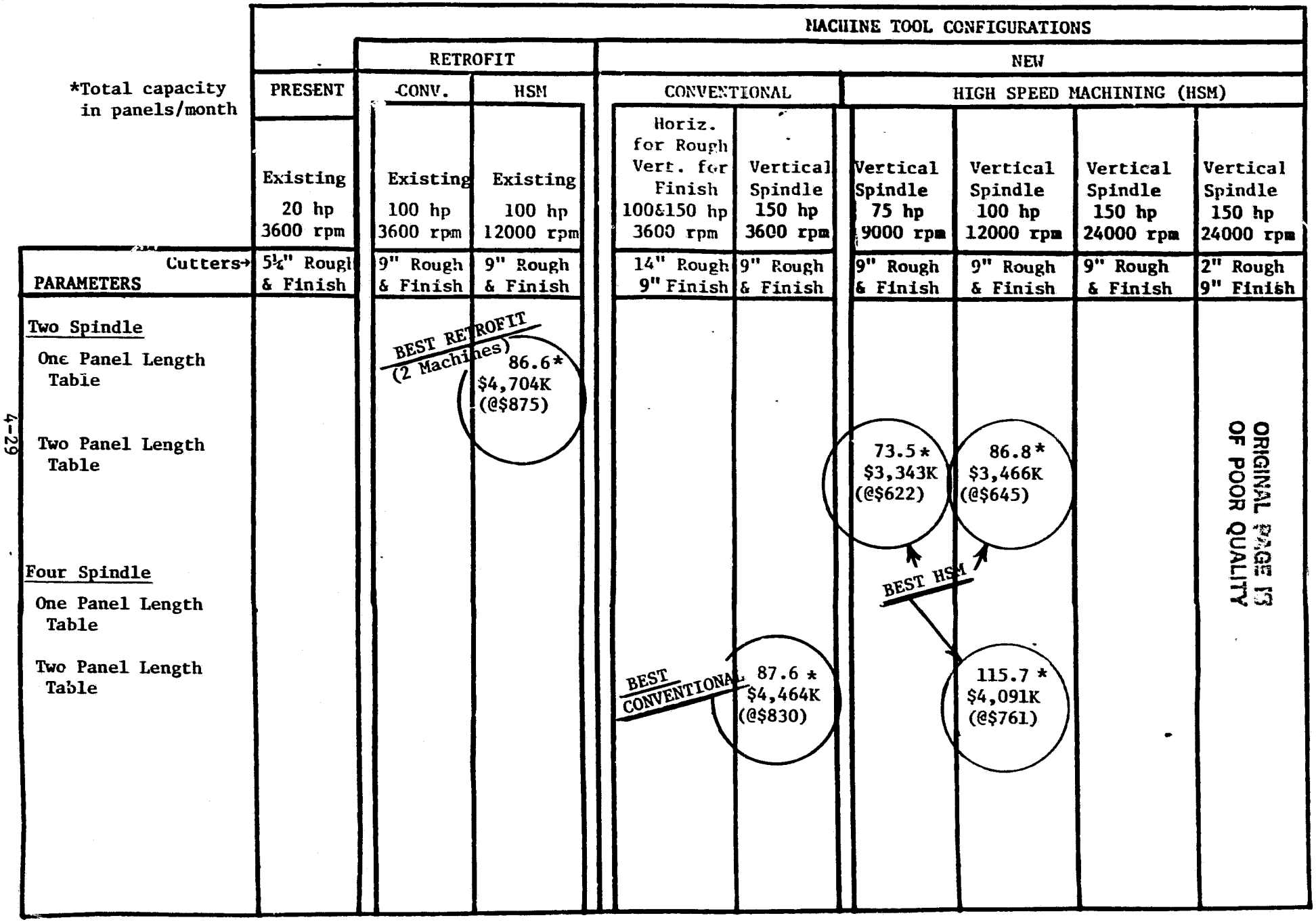
	MACHINE TOOL CONFIGURATIONS								
		RETROFIT		NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING (HSM)			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
One Spindle									
One Panel Length Table	3.9	16.7	28.9	15.6	17.7	25.8	29.9	41.7	40.5
Two Panel Length Table	–	–	–	19.1	22.2	36.7	45.6	80.1	75.9
Two Spindle									
One Panel Length Table	–	28.0	43.3	26.5	29.4	39.8	44.5	56.3	55.2
Two Panel Length Table	–	–	–	38.2	44.5	73.5	86.8 (91.2)	86.8 (160.1)	86.8 (151.7)
Four Spindle									
One Panel Length Table	–	–	–	45.5	49.8	62.1	69.6	85.0	83.8
Two Panel Length Table	–	–	–	74.9	87.6	115.7 (133.8)*	115.7 (174.4)*	115.7 (319.9)*	115.7 (303.5)*

Table 4-9. Estimated Panel Machining Capacities and Combined Costs ($)
of 15 Machine Tool Configurations Meeting 64 Panel Per Month Requirements

80 Percent Efficiency Level

	MACHINE TOOL CONFIGURATIONS								
	RETROFIT		NEW						
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING (HSM)			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
One Spindle									
One Panel Length Table									
Two Panel Length Table								80.1 $2,693K	75.9 $2,752K
Two Spindle									
One Panel Length Table									
Two Panel Length Table						73.5 $3,343K	86.8 $3,466K	86.8 $2,866K	86.8 $2,866K
Four Spindle									
One Panel Length Table							69.6 $4,208K	85.0 $3,588K	83.8 $3,599K
Two Panel Length Table				74.9 $5,331K	87.6 $4,464K	115.7 $4,136K	115.7 $4,091K	115.7 $3,633K	115.7 $3,633K

Table 4-10. Recommended Machine Tool Configurations vs Total Cost and Cost Per Panel.



It is assumed that two saddles for mounting the spindles will be available on each machine and that the new Allen Bradley #7320 controls recently installed on the machine are capable of controlling the two spindles simultaneously as reported.

b) New Conventional

The best choice for a new conventional machine is a two panel wide, two panel long gantry type machine with four 150 hp, 3,600 rpm vertical spindles. This configuration is projected to have a panel machining capacity of 87.6 panels per month and have a combined total machine investment plus labor cost of $4,464,000 or $830 per panel.

c) High Speed Machines (HSM)

Five different machine configurations appear to meet all three of the selection criteria. Three configurations were identified involving the the least cost.

The two best choices are both gantry type milling machines with two spindles and a single width, double length table. The two 100 hp, 12000 rpm vertical spindle machine provides a capacity of 86.8 panels per month at an estimated combined machine investment plus labor cost of $3,466,000 or $645 per panel.

The other best choice machine has two 75 hp, 9,000 rpm vertical spindles, a capacity of 73.5 panels per month and is estimated to have a combined machine investment plus labor cost of $3,343,000 or $622 per panel.

The third lowest cost producing HSM configuration is the two panel wide, two panel long, gantry type machine with four 100 hp, 12,000 rpm vertical spindles. This machine has a projected panel machining capacity of 115.7 panels per month at an estimated combined investment plus labor cost of $4,091,000 or $761 per panel.

4-7 IMPLEMENTATION PLANS

Before a decision on retrofitting existing equipment or purchasing new is made, careful attention should be paid to several factors. Time should be allowed in the implementation schedule for a detailed vibration analysis of the present or other machine being considered for retrofitting. Estimated vendor delivery times should be confirmed since delivery schedules can vary noticeably with work load.

The following factors are involved and should be considered before the new or retrofit machine is fully ready for operation.

Retrofit Machine

The information in Figure 4-7 is provided as a guide for scheduling for a retrofit HSM system to be installed on the present machine.

If a retrofit were to be made on this machine, schedule and budgetary provisions should also be provided for the updating of the electrical power supply and other items described in Section 5. The overall time from placing of order to full production readiness is expected to approach 12 months.

New Conventional or HSM Machine

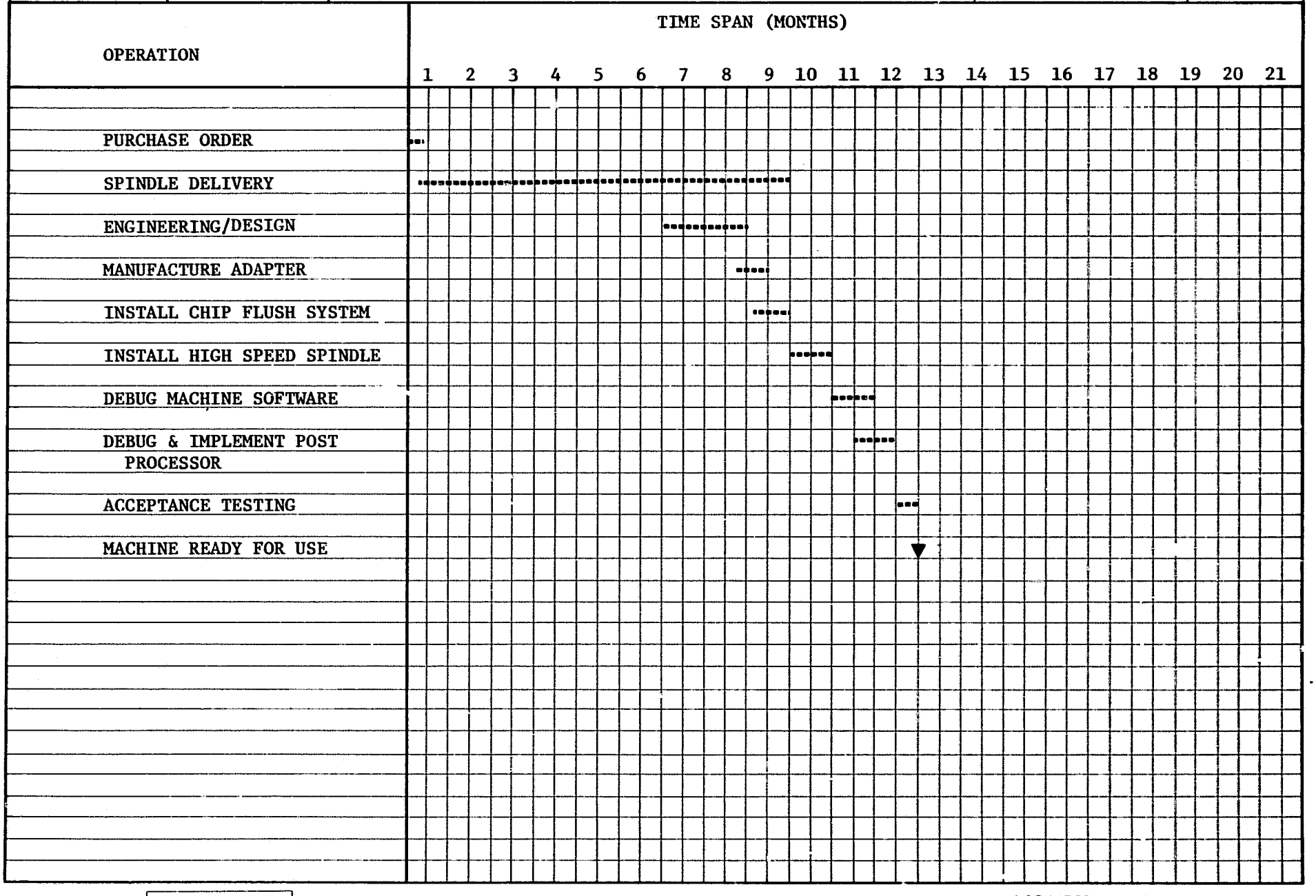
A scheduling and planning guide is provided in Figure 4-8 to be used for the procurement, installation and readying of either a new conventional or HSM machine. The lead times estimated by the machine tool builders contacted were essentially the same for either type of machine. However, some variation should be expected from particular machine tool builders. The overall time from placing of order to full production readiness is expected to be at least 18 months.

Other Considerations

Other activities should take place concurrent with the installation. For example, specific cutter determination and NC programming should be established.

SCHEDULE PLAN

MODEL	PLAN	TITLE	PREPARED BY:	DATE
		Figure 4-7. PROJECTED SCHEDULE FOR RETROFITTING PRESENT MACHINE FOR HIGH SPEED MACHINING		
ISSUE NO.	REFERENCE		APPROVED BY:	DATE



FORM LMSC 481-3 *Diazo Reproducible*

FIGURE 4-7

LOCKHEED MISSILES & SPACE COMPANY

SCHEDULE PLAN

MODEL	PLAN	TITLE	PREPARED BY:	DATE
		Figure 4-8. PROJECTED SCHEDULE FOR DELIVERY AND INSTALLATION OF NEW CONVENTIONAL OR HSM MACHINE		
ISSUE NO.	REFERENCE		APPROVED BY:	DATE

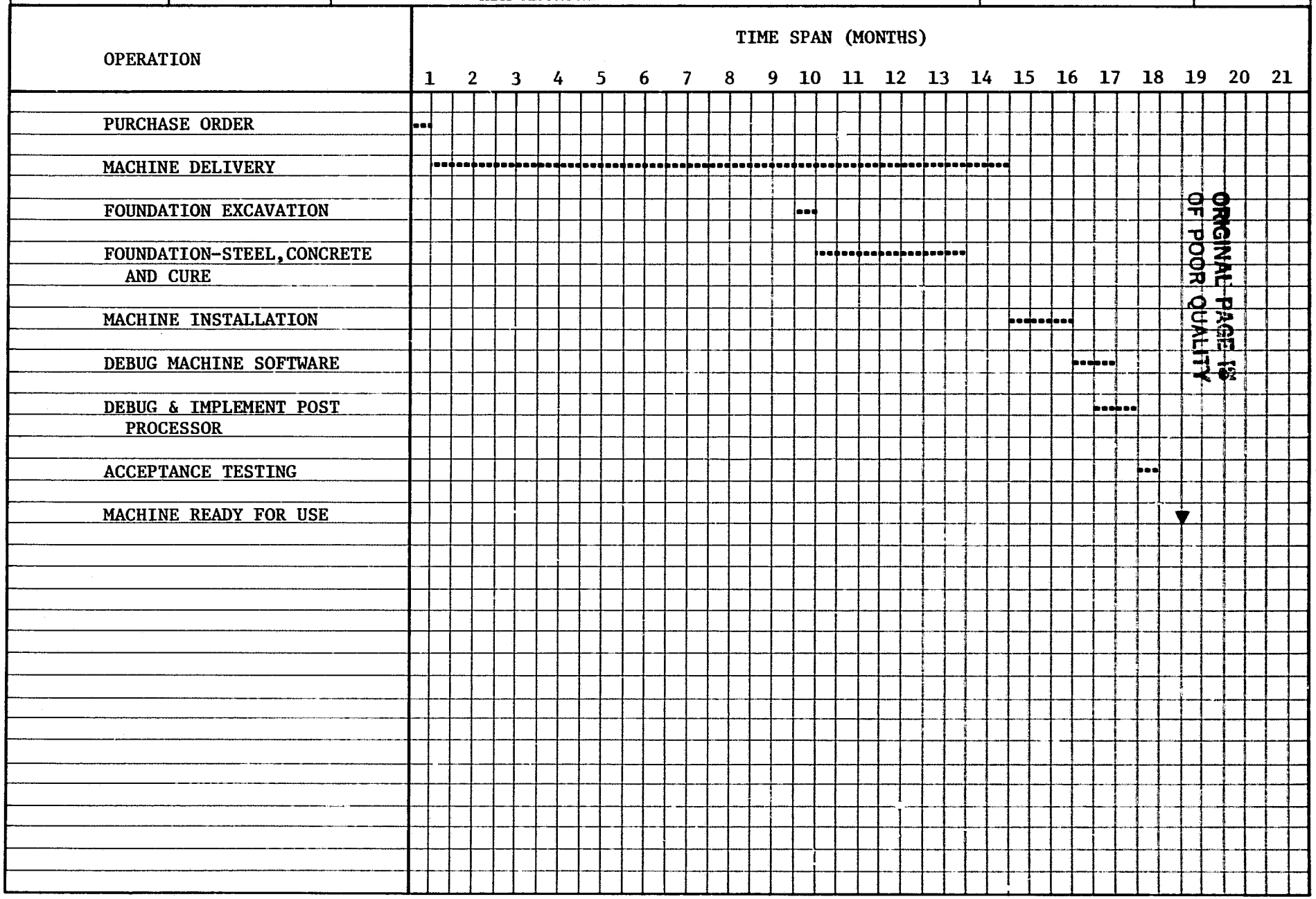


FIGURE 4-8

SECTION 5

GENERAL DISCUSSION

5-1 COMPARISON WITH TASK B PROJECTED MACHINING TIMES

The 6.0 hours machining time projected from the 4 foot by 8 foot panel machined in Task B (Table 6-1 of the Task B report) for the Cincinnati Milacron 75 hp single spindle machine compares very closely to the 5.9 hours total machining time estimated for the 75 hp, 9,000 rpm spindle machine (Table 4-2). The 4.48 hours projected in Task B for the 100 hp, single spindle machine also compares very closely to the 4.75 hours total machining time determined in Task A. The estimates in Task A and Task B were similar even though computed using different procedures.

5-2 PRODUCTION RATE OF PRESENT MACHINE

The 3.9 panel per month baseline production rate of the present machine is relatively low and is obviously limited by the low (20 hp) spindle motor. A more realistic baseline might be 16.7 panels per month projected as obtainable with a retrofit 100 hp, 3,600 rpm spindle (Figure 4-8). The 3.9 panel per month baseline production rate was calculated using current parameters for metal removal and assuming the starting stock to be 1.75 inch thick solid plate.

5-3 RETROFIT OF PRESENT MACHINE

When considering conversion of the present gantry type mill to HSM, the following decision making criteria should be included.

a. The current capital investment value of this machine was not included in this study. Only the additional retrofitting cost was considered.

b. The machine is approximately 20 years old but has been recently rebuilt and a new control has been added.

c. The present electrical power supply to the machine is reportedly capable of handling only 13 hp and will probably need to be replaced.

d. The gantry should operate at 200 ipm. Reportedly it can be operated currently at a maximum of 150 ipm. This limitation would need to be remedied.

e. Before a final decision to retrofit with large, powerful spindle motors is made, a detailed vibration analysis should be performed to insure a fully functional system. The presence of the current single 20 hp motor instead of two 100 hp motors (reportedly original equipment) may indicate problems of lack of rigidity and resulting vibrations.

f. A chip removal system should be defined and provided.

5-4 SELECTION OF GENERAL MACHINE TOOL CONFIGURATIONS

The best choice of the general machine configurations based on production capacity, labor cost, and machine investment cost is the two panel length, gantry type machine with two vertical spindles. Although the vertical panel machine concept has better chip removal characteristics, none of the machine tool builders contacted felt that it would be feasible to move the tall column required for an 11 foot wide panel at the feed rates desired for HSM.

The 100 hp, 12,000 rpm spindle is the best choice of spindle. The projected production capacity should be adequate and could be increased if the loading and unloading time were reduced.

The 150 hp, 24,000 rpm spindle coupled with the 1,000 ipm gantry feed is theoretically capable of considerably higher production rates than the lower rpm machines but the proposed designs need to be more fully proven. Furthermore, cutters are not yet available which would allow full utilization of machine potential.

The second choice of spindle is the well proven 75 hp, 9,000 rpm version. However, the monthly production capacity of this machine is somewhat lower than for the 100 hp, 12,000 rpm spindle.

Of the 41 machine configurations compared, 15 would be capable of meeting the capacity requirements of 64 panels per month at varying combined labor plus machine investment costs. However, eight of the 15 configurations involve the 150 hp, 24,000 rpm spindle which needs to be further proven.

5-5 CUTTERS

The study was based on the assumption that cutters are available (or shortly will be) which are capable of operating at the cutting speeds of interest. Availability was based on contacts with machine tool builders and cutter manufacturers. However, for the highest cutting speeds indicated (especially 56,549 sfpm) cutters are definately not yet available.

5-6 CHIP REMOVAL

The volume of chips produced is in direct relationship to the machining metal removal rate. At the very high metal removal rates under study, the removal requirements for the chips becomes significant and dictates a need for mechanized systems for chip removal.

The most highly recommended chip removal method for the gantry type milling machines is by vacuum. The chips are collected from an inlet located at each cutter and conducted to a common disposal point where coolant is reclaimed. The cost of such a system is estimated to be from $350,000 to $400,000 per machine. The cost for a chip removal system has not been included in the machine investment cost figures in this study.

Section 6

CONCLUSIONS

6-1 MACHINE TOOL CONFIGURATIONS

Based on the required 64 panel per month production rate (for 5,376 panels), the following machine tool configurations, cost savings and production rates are projected:

a. High Speed Machine (1) with (2) State-of-the-Art 75 hp High Speed Spindles.
   - o $17,935,000 Cost savings
   - o 73.5 panels per month rate

b. High Speed Machine (1) with (2)Advanced 100 hp High Speed Spindles
   - o $17,812,000 Cost savings
   - o 86.6 panels per month rate

c. New Conventional High-Capacity Machine (1) with (4) Conventional 150 hp Spindles
   - o $16,814,000 cost savings
   - o 87.6 panels per month rate

d. Retrofit for (2) Existing Machines each with (2) Advanced 100 hp High Speed Spindles
   - o $16,574,000 cost savings
   - o 86.6 panels per month rate

6-2 PROVEN HSM EQUIPMENT

Using proven HSM equipment, production rates could be increased from a baseline of 3.9 panels per month to 73.5 panels per month. The equipment used would be a one panel wide, two panel long gantry type mill with two 75 hp, 9,000 rpm spindles. The combined labor plus machine investment cost would be reduced from $3,958 to $622 per panel. The total estimated savings of 5,376 panels would be $17,935,000.

6-3 ADVANCED HSM EQUIPMENT

Advanced HSM equipment (not fully proven but at a high confidence level) would increase production rates from the current 3.9 panels per month to 86.6 panels per month. Equipment would be a one panel wide, two panel long gantry type machine with two 100 hp, 12,000 rpm vertical spindles. Labor plus machine investment cost would be reduced from a baseline of $3,958 to $645 per panel and estimated savings (on 5,376 panels) would be $17,812,000.

6-4 MAXIMUM PANEL AND SPINDLES BENEFITS

A two panel wide, two panel long gantry type machine with four 75 hp or greater HSM vertical spindles, would increase production rates from 3.9 panels per month to 115.7 panels per month (limited by load and unload time). The combined labor plus machine investment cost would be reduced from a baseline of $3,958 to $769 per panel for four 75 hp, 9,000 rpm spindles and have a projected total savings of $17,142,000 for 5,376 panels. A comparable reduction with four 100 hp, 12,000 rpm spindles would be from the baseline of $3,958 to $761 per panel at a projected total savings of $17,187,000.

6-5 RETROFITTING WITH HSM SPINDLES

Production rates could be increased from 3.9 panels per month currently to an estimated 43.4 panels per month by retrofitting two 100 hp, 12,000 rpm HSM spindles on the present gantry type mill. Two machines thus converted would be needed to achieve the 64 panel per month production requirement. The projected combined labor plus additional retrofitting machine investment cost (two machine) would be reduced from baseline $3,958 to $875 per panel for a total savings of $16,574,000 on 5,376 panels.

6-6 NEW CONVENTIONAL MACHINE

A new conventional machine could be used to increase production rates from 3.9 currently to 87.6 panels per month. This could be accomplished with a two panel wide, two panel long gantry type machine and four 150 hp, 3,600 rpm spindles. The projected combined labor plus machine investment cost would be reduced from baseline $3,958 to $830 per panel at a total estimated savings of $16,814,000 on 5,376 panels.

6-7 DEVELOPMENT HSM SPINDLES AND 1,000 IPM FEEDS

Extremely high production rates were indicated through use of HSM with 150 hp, 24,000 rpm spindle machines with 1,000 ipm gantry feed. However, these machines (and cutters to utilize their full potential) are not sufficiently proven to be recommended in this study. The potential of such a machine however, indicates an $18,106,000 cost savings (5,376 panels) for a four (4) spindle, two panel width, two panel length configuration. With unrestricted gantry speed and load/unload times, production rates of 320 panels per month were projected!

6-8 HORSEPOWER EFFECTS

Horsepower was the dominant factor regarding the metal removal rate during the rough machining operation regardless of rpm or cutting speed (sfpm).

6-9 DOMINANT FACTORS - METAL REMOVAL RATE

Rpm and gantry feed (ipm) were the dominant factors regarding the metal removal rate during the finishing operations. The production capacity of the machines increased as rpm and gantry feed were increased.

6-10 ADDED TABLE LENGTH

The addition of the second table length to allow machining to continue during loading and unloading, increased the production capacity and decreased the cost per panel in all instances.

6-11 LOAD/UNLOAD TIME

Loading and unloading time became a limiting factor at the high production capacities even for the two panel length machines.

6-12 HORIZONTAL VS VERTICAL SPINDLES

The machines with horizontal spindles for rough machining and vertical spindles for finish machining showed a lower production capacity and higher cost per panel than for comparable machines with vertical spindles only.

6-13 PANEL MOUNTING

Machines with vertical mounting of panels would appear to be best suited for convenient chip removal. At the current state of development, however, travel rates for the moveable columns are not competitive with the gantry type machines.

6-14 CHIP REMOVAL

Chip removal is a very important consideration. Currently, the most highly recommended system for large horizontal panels utilizes vacuum removal techniques that are proven and in use on other applications.and that can handle without problem the large chip volumes typical of hsm.

APPENDIX A

MACHINING OPERATION TIME

Table A-1. Determination of Machining Operation Time:
Rough Mill Pockets

(Based on One Spindle)

(XXX) values limited by travel feed restrictions	MACHINE TOOL CONFIGURATIONS								
		RETROFIT		NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9,000 rpm	Vertical Spindle 100 hp 12,000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9"& Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough & Finish	2"Rough 9" Finish
Cutter Diameter (in)	5-¼	9	9	14	9	9	9	9	2
No. of Teeth	4	8	8	8	8	8	8	8	3
Chip Load (in)	.0008	.007	.002	.007	.007	.007	.007	(.005)	.007
No. of Layers	4	7	7	3	5	23	22	23	3
No. of Passes per Pocket	8	7	7	12	5	23	22	23	15
Depth of Cut (axial) (in)	.475 max	.218	.218	2.8 (Max.)	2.8 max.	.066	.069	.066	.508
Depth of Cut (radial) (in)	5.25	9	9	.508	9	9	9	9	2
Cross-Section/Pass (sq. in.)	2.494	1.962	1.962	1.422	2.745	.594	.624	.597	1.016
Table Feed Used (ipm)	12	200 max	200 max	202	202	500	636	(1000)	504
Cu. In./Min.	30	392	392	287	549	297	397	597	512
Horsepower Required	13 max	98.1	98.1	71.8	137.0	74.3	99.2	149.2	128.0
Cutting Speed (sfpm)	4,948	8,482	28,274	13,195 8,482	8,482	21,206	28,274	56,549	12,566
Time Required (hrs)	32.256	1.813	1.813	2.766	1.295	2.368	1.716	(1.220)	1.426

Table A-2. Determination of Machining Operation Time: Finish Mill Bottom of Pockets
(9" Diameter Cutter, .100" Deep Except "Present" at CPC)

(Based on One Spindle)

	MACHINE TOOL CONFIGURATIONS								
		RETROFIT		NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING (HSM)			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Cutter Dia. (In.)	5-1/4	9	9	9	9	9	9	9	9
No. of Teeth	4	8	8	8	8	8	8	8	8
Chip Load	.0008	.003	.002*	.003	.003	.003	.003	.003	.003
No. of Layers	1	1	1	1	1	1	1	1	1
Total Passes/Pocket	2	1	1	1	1	1	1	1	1
Depth of Cut (Axial)	5.25	.100	.100	.100	.100	.100	.100	.100	.100
Depth of Cut (Radial)	.100	9	9	9	9	9	9	9	9
Cross-Section/Pass	.525	.900	.900	.900	.900	.900	.900	.900	.900
Table Feed Used	12	86	200*	86	86	216	288	576	576
Cu.in./min.	6.3	77	180*	77	77	194	257	515	515
Horsepower Required	1.6	19.4	45*	19.4	19.4	48.4	64.4	129	129
Cutting Speed (sfpm)	4,948	8,482	28,274	8,482	8,482	21,206	28,274	56,549	56,549
Hours Required	8.064	.593	.259*	.593	.593	.243	.181	.084	.084

*Reduced due to table feed limitation of 200 ipm.

Table A-3. Determination of Machining Operation Time: Mill T-Ribs
(Based on One Spindle)

	MACHINE TOOL CONFIGURATIONS								
		RETROFIT		NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Cutter Diameter (in)	4	4	4	4	4	4	4	4	4
No. of Teeth	6	4	4	4	4	4	4	4	4
Chip Load (in.)	.0019	.003	.003	.003	.003	.003	.003	.003	.003
No. of Layers	2	2	2	2	2	2	2	2	2
Total # of passes/ Rib	4	4	4	4	4	4	4	4	4
Depth of Cut (axial) (in)	.725 max.	.725	.725	.725	.725	.725	.725	.725	.725
Depth of Cut (Radial (in)	.575	.575	.575	.575	.575	.575	.575	.575	.575
Cross - Section/Pass (sq. in.)	.417	.417	.417	.417	.417	.417	.417	.417	.417
Table Feed Used (ipm)	40	43	144	43	43	108	144	288	288
Cu. In./Minute	17	18	60	18	18	45	60	120	120
Horsepower Required	4.3	4.5	15.0	4.5	4.5	11.3	15.0	30.0	30.0
Cutting Speed (sfpm)	3,770	3,770	12,566	3,770	3,770	9,425	12,566	25,133	25,133
Hours Required	4.838	4.493	1.382	4.493	4.493	1.728	1.382	.691	.691

Table A-4. Determination of Machining Operation Time: Mill Edge of T's and Radii (Based on One Spindle)

	MACHINE TOOL CONFIGURATIONS								
		RETROFIT		NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5½" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Cutter Diameter(in)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
# of Teeth	4*	4	4	4	4	4	4	4	4
Chip Load (in)	.0028	.003	.003	.003	.003	.003	.003	.003	.003
No. of Layers	1	1	1	1	1	1	1	1	1
Total # of Passes/ Rib	2	2	2	2	2	2	2	2	2
Depth of Cut (Axial)	1.125	1.125	1.125	1.125	1.125	1.125	1.125	1.125	1.125
Depth of Cut (Radial) (in)	.296	.296	.296	.296	.296	.296	.296	.296	.296
Cross - Section/Pass (sq. in.)	.333	.333	.333	.333	.333	.333	.333	.333	.333
Table Feed Used (ipm)	40	43	144	43	43	108	144	288	288
Cu. In./Min.	13	14	48	14	14	36	48	96	96
Horsepower Required	3.3	3.5	12.0	3.5	3.5	9.0	12.0	24.0	24.0
Cutting Speed (sfpm)	2,356	2,356	7,854	2,356	2,356	5,891	7,854	15,708	15,708
Hours Required	2.419	2.246	.691	2.246	2.246	.864	.691	.346	.346

*Assumed Value

APPENDIX B

MACHINE RUN CALCULATIONS

Table B-1 Present Method — 20HP (13 [illegible], 3500 RPM

MACHINE RUN CALCULATIONS

ITEM NO.	ELEMENT DESCRIPTION	CUT-TER	LOC. a	APP +OT b	TOT. LOC. c	STD. HRS./ INCH d	OCC e	MACH. TIME e
	Mill Top of Tee 1 Pass	5½			240.00	.0014	12	.336
	12 ipm							
	Rough Mill Packet 4 Layers x 2 Passes	5¼			240.00	.0014	8X12	32.256
	12 ipm							
	Finish Mill Packet 2 Passes	5¼			240.00	.0014	2X12	2.016
	12 ipm							
	Mill Under T-Rib 2 Passes	4			240.00	.00042	2X24	4.032
	40ipm (.0019"chip load) 6 teeth							
	Mill Edge of Tee 1 Pass	2½EM			240.00	.00042	24	2.419
	40 ipm (Assuming 4 Teeth)							
	Mill Periphery 1 Pass	2½EM			610.00	.00042	1	.256
	40ipm (Assuming 4 Teeth)							
	Mill Taper on Tee 1 Pass	2"EM			5.00	.00055	24	.040
	30 ipm							
							229	
							- 4	
	Milling Time							51.925
	Cutter Reposition				.0025 X		225	.563
	Total Machining Time (hrs)							52.468
	(Using 4 layers for Roughing)							

TOTAL MACHINE RUN - (Transfer to Front Page)

NOTE: a + b = c x d x e = f

88-02/4-6-66

Table B-2 7" Cutter, 2 Teeth, Roughing, 200 IPM, Finishing, 86 IPM

MACHINE RUN CALCULATIONS

ITEM NO.	ELEMENT DESCRIPTION	CUT-TER	LOC. a	APP +OT b	TOT. LOC. c	STD. HRS./ INCH d	OCC e	MACH. TIME e
	Mill Top of Tee 1 Pass	7"			240.00	.00017	12	.041
	86 ipm							
	Rough Mill Pocket 7 Layers	7"			240.00	.000028	7X13	1.313
	=200 ipm							
	Finish Mill Pocket 1 Pass				240.00	.00019	7X3	.532
	86 ipm							
	Mill T-Rib	4"			240.00	.00032	2X24	4.443
	43 ipm 4 Teeth							
	Mill Edge of Tee	2½"			240.00	.00039	24	2.246
	43 ipm 4 Teeth							
	Mill Periphery	2½"			610.00	.00039	1	.238
	43 ipm 4 Teeth							
	Mill Taper on Tee 1 Pass	2"			3.00	.00055	24	.040
	30 ipm 4 Teeth							
							213	
	Milling Time						- 4	4.270
	Cutter Reposition		.0025	x			209	.523
	Total Machining Time (hrs)							10.473

TOTAL MACHINE RUN -
(Transfer to Front Page)

NOTE: a + b = c x d x e = f

Table B-3 2" Cutter, 2 Teeth, Retrofit 100 HP, 12,000 R.P.M., 200 IPM

MACHINE RUN CALCULATIONS

ITEM NO.	ELEMENT DESCRIPTION	CUT-TER	LOC. a	APP +OT b	TOT. LOC. c	STD. HRS./ INCH d	OCC e	MACH. TIME e
	Mill Top of Tee 1 Pass	2"			240.00	.000083	12	.239
	~~200~~ 200 ipm (.002" chip load)							
	Rough Mill Pocket 7 Layers	2"			240.00	.000083	7x12	1.213
	~~672~~ 200 ipm (.002" chip load)							
	Finish Mill Pocket 1 Pass	2"			240.00	.000083	1x12	.239
	~~288~~ 200 ipm							
	Mill T-Rib	2½"			240.00	.000083	2x12	.478
	144 ipm							
	Mill Edge of Tee	2½"			240.00	.000083	2x12	.478
	144 ipm							
	Mill Periphery	2½"			240.00	.000083	1	.239
	Mill Taper on Tee	2"			8.00	.000556	24	.040
	30 ipm							
							213	
	Milling Time						+1	4.017
	Cutter Reposition		.0025		x		209	.523
	Total Machining Time (hrs)							5.020

NOTE: The crossed out feed rates were reduced due to the 200 ipm gantry feed limitation.

TOTAL MACHINE RUN - (Transfer to Front Page)

NOTE: a + b = c x d x e = f

Table B-4 14" Wheel, Cutter (Roughing), 9" (Finishing), 100 HP @ 15 HP

MACHINE RUN CALCULATIONS

ITEM NO.	ELEMENT DESCRIPTION	CUT-TER	LOC. a	APP +OT b	TOT. LOC. c	STD. HRS./ INCH d	OCC e	MACH. TIME e
	Mill Top of Tee 1 Pass	2½			240.00	.00037	12	.053
	43 ipm 4 Flute							
	Rough Mill Pocket 3 layers x 4 Passes	14"WH			240.00	.00008	12×12	2.766
	202 ipm 8 Teeth							
	Finish Mill Pocket 1 Pass	9			240.00	.00037	12	.053
	43 ipm 8 Teeth							
	Mill Under T-Rib 2 Passes	4			240.00	.00037	12	1.275
	43 ipm 4 Teeth at .003" Chip Load							
	Mill Base of Tee 1 Pass	2½"EM			240.00	.00037	24	2.346
	43 ipm 4 Teeth							
	Mill Periphery 1 Pass	2½"EM			240.00	.00037		.222
	43 ipm 4 Teeth							
	Mill Taper on Tee 1 Pass	2"EM			2.00	.00055	24	.040
	30 ipm							
							266	
	Milling Time (200 ipm)							10.923
	Cutter Reposition (for 4 Spindle Machines)				.0025	x	266	.665
	Total Machining Time (Hrs) (4 Spindles)							11.588
	Milling Time (300 ipm for 1 or 2 Spinde Machines)							10.923
	Cutter Reposition				.00167	x	266	.444
	Total Machining Time (Hrs)							11.367
						TOTAL MACHINE RUN - (Transfer to Front Page)		

NOTE: a + b = c x d x e = f

86-62/4-E-66

ORIGINAL PAGE IS
OF POOR QUALITY

Table B-5 9" Diameter [illegible] 150 HP [illegible]

MACHINE RUN CALCULATIONS

ITEM NO.	ELEMENT DESCRIPTION	CUTTER	LOC. a	APP +OT b	TOT. LOC. c	STD. HRS./INCH d	OCC e	MACH. TIME e
	Mill Top of Tee 1 Pass	9"			[illegible]	[illegible]	[illegible]	[illegible]
	25 ipm 2 Teeth							
	[illegible]	9"			[illegible]	[illegible]	[illegible]	1.2[illegible]
	[illegible] ipm 2 Teeth							
	Finish Mill [illegible] 1 Pass	9"			[illegible]	[illegible]	[illegible]	[illegible]
	[illegible] ipm 2 Teeth							
	Mill T-Slot 2 Passes	[illegible]			240.00	.00[illegible]	[illegible]	[illegible]
	43 ipm 4 Teeth							
	Mill Edge of Tee 1 Pass	2½"EM			240.00	.00021	24	2.24[illegible]
	43 ipm 4 Teeth					?		
	Mill Periphery 1 Pass	2½"EM			610.00	.00039	1	.237
	86 ipm 4 Teeth							
	Mill Taper on Tee 1 Pass	2"EM			3.00	.00055	24	.040
	30 ipm							
							187	
	Machining Time/Spindle for 4 Spindle Machines (250 ipm)						-4	
	Milling Time							9.452
	Cutter Reposition			.0025	x		183	.457
	Total Machining Time (hrs)							[illegible]
	Machining Time/Spindle for 1 or 2 Spindle Machines (300 ipm)							
	Milling Time							9.452
	Cutter Reposition			.00167	X		183	.303
	Total Machining Time (hrs)							9.755

TOTAL MACHINE RUN - (Transfer to Front Page)

NOTE: a + b = c x d x e = f

8S-62/4-6-66

[illegible] T-6 [illegible]

MACHINE RUN CALCULATIONS

ITEM NO.	ELEMENT DESCRIPTION	CUT-TER	LOC. a	APP +OT b	TOT. LOC. c	STD. HRS./ INCH d	OCC e	MACH. TIME e
	[illegible] Tee 1 Pass	2"			240.00	.0[illegible]72	12	.22[illegible]
	216 ipm							
	Rough Mill Pocket 23 Layers x 13 Passes	9"			240.00	.000088	23x13	2.362
	504 ipm							
	Finish Mill Pocket 1 Pass	9"			240.00	.000378	1x13	.245
	216 ipm							
	Mill T-Rib 2 Passes	4"			240.00	.00315	2x24	.[illegible]6[illegible]
	108 ipm + Teeth							
	Mill Each Side of Tee 1 Pass	2½"			240.00	.00315	24	.[illegible]6[illegible]
	108 ipm 4 Teeth							
	Mill Periphery 1 Pass	2½"			610.00	.00315	1	.192
	108 ipm 4 Teeth							
	Mill Taper on Tee 1 Pass	2"			5.20	.00055	24	.069
	30 ipm							
							421	
	Machining Time/Spindle for 4 Spindle Machines (200 ipm?)						-4	
	Milling Time						(2)	5.560
	Cutter Repositioning		.0025	x			417	1.043
	Total Machining Time (hrs)							5.603
	Machining Time/Spindle for 1 or 2 Spindle Machines (600 ipm)							5.560
	Milling Time							.346
	Total Machining Time (hrs)							5.906

TOTAL MACHINE RUN - (Transfer to Front Page)

NOTE: a + b = c x d x e = f

86-62/4-6-66

Table B-7 9" Diameter Cutter 8 Teeth, 100 HP, [illegible] RPM

MACHINE RUN CALCULATIONS

ITEM NO.	ELEMENT DESCRIPTION	CUT-TER	LOC. a	APP +OT b	TOT. LOC. c	STD. HRS./ INCH d	OCC e	MACH. TIME e
	Mill Top of Tee 1 Pass	9"			240.00	.000058	12	.167
	222 ipm							
	Rough Mill Pocket 22 Layers	9"			240.00	.000325	22x18	1.716
	Finish Mill Pocket 1 Pass	9"			240.00	.000058	1x18	.242
	222 ipm							
	Mill T-Rib 2 Passes	9"			240.00	.000172	2x24	1.032
	144 ipm 4 Teeth							
	Mill Edge of Tee 1 Pass	2½"			240.00	.000172	24	.691
	144 ipm 4 Teeth							
	Mill Periphery 1 Pass	2½"			610.00	.000172	1	.073
	144 ipm 4 Teeth							
	Mill Taper on Tee 1 Pass	2"			8.00	.000575	24	.092
							408	
							- 4	
	Milling Time for 1 or 2 Spindle Machines							4.253
	Cutter Repositioning		.00135		X		434	.505
	Total Machining Time (hrs)							4.758
	Milling Time for 4 Spindle Machines							4.497
	Cutter Repositioning		.00285		X		1207	.523
								5.020

TOTAL MACHINE RUN - (Transfer to Front Page)

NOTE: a + b = c x d x e = f

Table B-8 7" Diameter Cutter, 8 Teeth, 150 HP, 24,000 RPM

MACHINE RUN CALCULATIONS

ITEM NO.	ELEMENT DESCRIPTION	CUTTER	LOC. a	APP +OT b	TOT. LOC. c	STD. HRS./ INCH d	OCC e	MACH. TIME e
	Mill Top of Tee 1 Pass	9"			240.00	.000029	12	.084
	576 ipm							
	Rough Mill Pocket 23 Layers	9"			240.00	.000017	23x13	1.240
	~~1344~~ 1000 ipm (max. of machine)							
	Finish Mill Pocket 1 Pass	9"			240.00	.000029	12	.084
	576 ipm							
	Mill T-Rib 2 Passes	4"			240.00	.000036	48	.311
	288 ipm							
	Mill Edge of Tee 1 Pass	2 1/2"			240.00	.000036	24	.207
	288 ipm							
	Mill Periphery 1 Pass	2 1/2"			610.00	.000016	1	.037
	288 ipm							
	Mill Taper on Tee 1 Pass	2"			3.00	.000155	24	.045
							420	
							-4	
	Milling Time							2.502
	Cutter Repositioning		.0005	X			416	.208
	Total Machining Time (hrs)							2.710

NOTE: The crossed out feed rate was reduced due to the 1,000 ipm gantry feed limitation.

TOTAL MACHINE RUN - (Transfer to Front Page)

NOTE: a + b = c x d x e = f

86-02/4-6-86

APPENDIX C

FLOOR-TO-FLOOR MACHINING TIME AND MONTHLY PANEL MACHINING CAPACITY

Table C-1. Total Floor-to-Floor Machining Time and Monthly Panel Machining Capacity

One Spindle Machine

One Panel Length Table

** Requires 2 spindles but 1 used at a time

	MACHINE TOOL CONFIGURATIONS								
		RETROFIT		NEW					
	PRESENT 1 Spindle	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough **9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Machining Time (hours)	52.468	10.493	5.020	11.367	9.758	5.906	4.755	2.710	2.860
Break, Fatigue and Personal Time (hrs) (20% of Machining Time)	10.494	2.099	1.004	2.273	1.952	1.181	.951	.542	.572
Shop Machining Time (hours)	62.962	12.592	6.024	13.640	11.710	7.087	5.706	3.252	3.432
Panel Loading and Unloading Time (hours)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Total Floor-To-Floor Time (hours)	65.962	15.592	9.024	16.640	14.710	10.087	8.706	6.252	6.432
Monthly Panel Capacity/2 Shifts (no. panels)	4.9	19.5	36.1	19.6	22.1	32.3	37.4	52.1	50.6

Table C-2. Total Floor-to-Floor Machining Time and Monthly Panel Machining Capacity
Two Spindle Machine (Machining One Panel)

One Panel Length Table

	MACHINE TOOL CONFIGURATIONS								
		RETROFIT		NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	* Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Machining Time (hrs) (inc. cutter Positioning)	52.468 ref.	5.247	2.510	5.684	4.879	2.953	2.378	1.355	1.430
Break, Fatigue and Personal Time(hrs) 20% of Machining Time	10.494 ref.	1.049	.502	1.137	.976	.591	.476	.271	.286
Shop Machining Time (hours)	62.962 ref.	6.296	3.012	6.821	5.855	3.544	2.854	1.626	1.716
Panel Loading and Unloading Time (Hours)	3.0 ref.	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Total Floor-to-Floor Time (Hours)	65.962 ref.	9.296	6.012	9.821	8.855	6.544	5.854	4.626	4.716
Monthly Panel Capacity/2 Shifts (No. Panels)	4.9 ref.	35.0	54.1	33.1	36.8	49.7	55.6	70.4	69.0

*Requires 4 spindles but only 2 used at a time

Table C-3. Total Floor-to-Floor Machining Time and Monthly Panel Machining Capacity
Four Spindle Machine (Machining Two Panels)

One Panel Length Table

	MACHINE TOOL CONFIGURATIONS								
	RETROFIT			NEW					
	PRESENT 1 Spindle	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Machining Time (hrs)	52.468	-	-	2.897	2.478	1.651	1.255	.678	.715
Break, Fatigue and Personal Time (hrs) (20% of Machining Time)	10.494	-	-	.579	.496	.295	.238	.136	.143
Shop Machining Time (Hours)	62.962	-	-	3.476	2.974	1.946	1.493	.814	.858
Panel Loading and Unloading Time (hrs)	3.0	-	-	2.250	2.250	2.250	2.250	2.250	2.250
Total Floor-to-Floor Time (Hours)	65.962	-	-	5.726	5.224	4.196	3.743	3.064	3.108
Monthly Panel Capacity 2 Shifts (No. Panels)	4.9	-	-	56.8	62.3	77.6	87.0	106.2	104.7

Table C-4. Total Floor-to-Floor Machining Time and Monthly Panel Machining Capacity (One Spindle Machine)

Two Panel Length Table

	MACHINE TOOL CONFIGURATIONS								
	RETROFIT		NEW						
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Machining Time (Hrs) (Incl. Cutter Positioning)	52.468	-	-	11.367	9.758	5.906	4.755	2.710	2.860
Break, Fatigue and Personal Time (Hrs) (20% of Machining Time)	10.494	-	-	2.273	1.952	1.181	.951	.542	.572
Shop Machining Time (Hours)	62.962	-	-	13.640	11.710	7.087	5.706	3.252	3.432
Additional Panel Loading and Unloading Time (Hours)	-	-	-	0	0	0	0	0	0
Total Floor-to-Floor Time (Hours)	65.962	-	-	13.640	11.710	7.087	5.706	3.252	3.432
Monthly Panel Capacity/2 Shifts (# panels)	4.9	-	-	23.9	27.8	45.9	57.0	100.1	94.8

Table C-5. Total Floor-to-Floor Machining Time and Monthly Panel Machining Capacity
Two Spindle Machine

Two Panel Table Length

(XXX) Values not limited by load/unload times

	MACHINE TOOL CONFIGURATIONS									
	PRESENT	RETROFIT		NEW						
		CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING (HSM)				
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertic Spind
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish	
Machining Time (hrs) (incl. cutter Positioning)	52.468	-	-	5.684	4.879	2.953	2.378	1.355	1.430	
Break, Fatigue and Personal Time (Hrs) (20% of Machining Time)	10.494	-	-	1.137	.976	.591	.476	.271	.286	
Shop Machining Time (Hours)	62.962	-	-	6.821	5.855	3.544	2.854	1.626	1.716	
Additional Panel Loading and Unloading Time (Hours)	-	-	-	0	0	0	.146	1.374	1.284	
Total Floor-to-floor Time (Hours)	65.962	-	-	6.821	5.855	3.544	3.000 (2.854)	3.000 (1.626)	3.000 (1.716)	
Monthly Panel Capacity/2 Shifts (# Panels)	4.9	-	-	47.7	55.6	91.8	108.5 (114.1)	108.5 (200.2)	108.5 (189.7)	

Table C-6. Total Floor-to-Floor Machining Time and Monthly Panel Machining Capacity

Four Spindle Machine

Two Panel Length Table

(XXX) Values not limited by load/ unload time

*** Values limited by gantry feed

	MACHINE TOOL CONFIGURATIONS								
	PRESENT	RETROFIT		NEW					
		CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Machining Time (Hrs) (Incl. Cutter Positioning)	52.468	-	-	2.894***	2.478***	1.651	1.255	.678	.715
Break, Fatigue and Personal Time (Hrs) (20% of Machining Time)	10.494	-	-	.579	.496	.295	.238	.136	.143
Shop Machining Time (Hours)	62.962	-	-	3.476	2.974	1.946	1.493	.814	.858
Additional Panel Loading and Unloading Time (Hours)	-	-	-	0	0	.304	.757	1.436	1.594
Total Floor-to-Floor Time (Horus)	65.962	-	-	3.476	2.974	2.250 (1.946)	2.250 (1.493)	2.250 (.814)	2.250 (.858)
Monthly Panel Capacity/2 Shifts (# Panels)	4.9	-	-	93.6	109.4	144.7 (167.3)	144.7 (218.0)	144.7 (399.9)	144.7 (379.4)

APPENDIX D

LABOR COSTS

Table D-1. Cost ($): Per Panel and Per 5,376 Panels

One Panel Length Table

	MACHINE TOOL CONFIGURATIONS								
	PRESENT	RETROFIT		NEW					
		CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5½" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
One Spindle									
Hours/Panel	65.962	15.592	9.024	16.640	14.710	10.087	8.706	6.252	6.432
$/Panel	3,958	936	541	998	883	605	522	375	386
$/5,376 Panels	21,278K	5,031K	2,908K	5,365K	4,474K	3,252K	2,806K	2,016K	2,075K
Two Spindle									
Hours/Panel	-	9.296	6.012	9.821	8.855	6.544	5.854	4.626	4.716
$/Panel	-	558	361	589	531	393	351	278	283
$/5,376 Panels	-	3,000K	1,941K	3,166K	2,855K	2,113K	1,887K	1,495K	1,521K
Four Spindle									
Hours/Panel	-	-	-	5.726	5.224	4.196	2.743	3.064	3.108
$/Panel	-	-	-	344		252	225	184	186
$/5376 Panels	-	-	-	1,849K	1,683K	1,355K	1,209K	989K	1,000K

Table D-2. Labor Cost ($): Per Panel and Per 5,376 Panels

Two Panel Length Table

(XXX) Values not limited by load/unload times

	MACHINE TOOL CONFIGURATIONS								
		RETROFIT		NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	½" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
One Spindle									
Hours/Panel	65.962	-	-	13.640	11.710	7.087	5.706	3.252	3.432
$/Panel	3,958	-	-	818	703	425	342	195	206
$/5376 Panels	21,278K	-	-	4,398K	3,779K	2,285K	1,839K	1,048K	1,107K
Two Spindle									
Hours/Panel	-	-	-	6,821	5,855	3,544	3,000 (2.854)	3,000 (1.626)	3.000 1.716)
$/Panel	-	-	-	409	351	213	180 (171)	180 (98)	180 (103)
$/5,376 Panels	-	-	-	2,199K	1,887K	1,145K	968K (919K)	968K (527K)	968K (554K)
Four Spindle									
Hours/Panel	-	-	-	3,476	2,974	2.250 (1.946)	2.250 (1.493)	2.250 (.814)	2.250 (.858)
$/Panel	-	-	-	209	178	135 (117)	135 (90)	135 (49)	135 (51)
$/5376 Panels	-	-	-	1.124K	957K	726K (629K)	726K (484K)	726K (263K)	726K (274K)

APPENDIX E

MACHINE INVESTMENT COST

E-1 One Spindle (One Panel Width) - One Panel Length Table

E-2 Two Spindle (One Panel Width) - One Panel Length Table

E-3 Four Spindle (Two Panel Width) - One Panel Length Table

E-4 One Spindle (One Panel Width) - Two Panel Length Table

E-5 Two Spindle (One Panel Width) - Two Panel Length Table

E-6 Four Spindle (Two Panel Width) - Two Panel Length Table

Table E-1. Machine Investment Cost ($) per Panel and Per 5,376 Panels
One Spindle (One Panel Width)

One Panel Length Table

	MACHINE TOOL CONFIGURATIONS								
	PRESENT	RETROFIT		NEW					
		CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Cost of Machine (FOB Huntsville)	0	0	0	1,900K	1,750K	1,400K	1,500K	1,400K	1,400K
Cost of Additions	-	50K	235K	-	-	-	-	-	-
Vacuum Chuck (if separate)	-	-	-	225K	225K	225K	225K	-	-
Installation (Incl. Foundation)	-	1K	5K	72.5K	72.5K	72.5K	72.5K	72.5K	72.5K
Debug and Test	-	-	2K	12K	12K	12K	12K	12K	12K
Total Additional Machine Cost	-	51K	242K	2,209.5K	2,059.5K	1,709.5K	1,809.5K	1,484.5K	1,484.5K
Total Additional Machine Cost/Panel (Based on 5,376 Panels)	0	9	45	411	383	318	337	276	276

Table E-2. Machine Investment Cost ($) per Panel and per 5,376 Panels
Two Spindle (One Panel Width)

One Panel Length Table

	MACHINE TOOL CONFIGURATIONS								
	RETROFIT		NEW						
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	1 Spindle								
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Cost of Machine	0	0	0	2,200K	1,900K	1,550K	1,850K	1,650K	1,650K
Cost of Additions	-	100K	400K	-	-	-	-	-	-
Vacuum Chuck (If Separate)	-	-	-	225K	225K	225K	225K	-	-
Installation (incl. Foundation)	-	1.5K	7.5K	73K	73K	73K	73K	73K	73K
Debug and Test	-	-	3K	13K	13K	13K	13K	13K	13K
Total Additional Machine Cost	-	101.5K	410.5K	2,511K	2.211K	1.861K	2.161K	1.736K	1.736K
Total Additional Machine Cost/Panel (Based on 5,376 Panels)	0	19	76	467	411	346	402	323	323

Table E-3. Machine Investment Cost ($) per Panel and per 5,376 Panels
Four Spindle (Two Panel Width)

One Panel Length Table

	MACHINE TOOL CONFIGURATIONS								
	RETROFIT			NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	L Spindle								
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Cost of Machine (FOB Huntsville)	-	-	-	3,100K	2,400K	2,400K	2,500K	2,500K	2,500K
Cost of Additions	-	-	-	-	-	-	-	-	-
Vacuum Chuck (If Separate)	-	-	-	400K	400K	400K	400K	-	-
Installation (incl. Foundation)	-	-	-	82.5K	82.5K	82.5K	82.5K	82.5K	82.5K
Degub and Test	-	-	-	16.5K	16.5K	16.5K	16.5K	16.5K	16.5K
Total Machine Cost	-	-	-	3,599K	2,899K	2,899K	2,999K	2,599K	2,599K
Total Machine Cost/ Panel (based on 5,376 panels)	-	-	-	669	539	539	558	483	483

Table E-4. Machine Investment Cost ($) per Panel and per 5,376 Panels
One Spindle (One Panel Width)

Two Panel Length Table

	MACHINE TOOL CONFIGURATIONS								
	PRESENT	RETROFIT		NEW					
		CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
PARAMETERS / Cutter →	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Cost of Machine (FOB Huntsville)	-	-	-	2,150K	2,000K	1,550K	1,650K	1,550K	1,550K
Cost of Additions	-	-	-	-	-	-	-	-	-
Vacuum Chuck (if separate)	-	-	-	400K	400K	400K	400K	-	-
Installation (Incl. Foundation)	-	-	-	82.5K	82.5K	82.5K	82.5K	82.5K	82.5K
Debug and Test	-	-	-	12K	12K	12K	12K	12K	12K
Total Machine Cost	-	-	-	2,644.5K	2,494.5K	2,044.5K	2,144.5K	1,644.5K	1,644.5K
Total Machine Cost/ Panel (Based on 5,376 Panels)	-	-	-	492	464	380	399	306	306

Table E-5. Machine Investment Cost ($) per Panel and per 5,376 Panels
Two Spindle (One Panel Width)

Two Panel Length Table

	MACHINE TOOL CONFIGURATIONS								
	RETROFIT			NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5½" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Cost of Machine (FOB Huntsville)	-	-	-	2,450K	2,150K	1,700K	2,000K	1,800K	1,800K
Cost of Additions	-	-	-	-	-	-	-	-	-
Vacuum Chuck (If Separate)	-	-	-	400K	400K	400K	400K	-	-
Installation (incl. Foundation)	-	-	-	85K	85K	85K	85K	85K	85K
Debug and Test	-	-	-	13K	13K	13K	13K	13K	13K
Total Machine Cost	-	-	-	2,948K	2,648K	2,198K	2,498K	1,898K	1,898K
Total Machine Cost/ Panel (based on 5,376 panels)	-	-	-	548	493	409	465	353	353

Table E-6. Machine Investment Cost ($) per Panel and per 5,376 Panels
Four Spindle (Two Panel Width)

Two Panel Length Table

	MACHINE TOOL CONFIGURATIONS								
		RETROFIT		NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Cost of Machine (FOB Huntsville)	-	-	-	3,400K	2,700K	2,700K	2,800K	2,800K	2,800K
Cost of Additions	-	-	-	-	-	-	-	-	-
Vacuum Chuck (if separate)	-	-	-	700K	700K	700K	700K	-	-
Installation (inc. Foundation)	-	-	-	90K	90K	90K	90K	90K	90K
Debug and Test	-	-	-	16.5K	16.5K	16.5K	16.5K	16.5K	16.5K
Total Machine Cost	-	-	-	4,206.5K	3,506.5K	3,506.5K	3,606.5K	2,906.5K	2,906.5K
Total Machine Cost/ Panel (Based on 5,376 Panels)	-	-	-	782	652	652	671	541	541

APPENDIX F

MACHINE INVESTMENT PLUS LABOR COSTS

Table F-1. Combined Machine Investment Plus Labor per Panel and per 5,376 Panels ($)

One Panel Length Table – One Spindle

	MACHINE TOOL CONFIGURATIONS								
	PRESENT	RETROFIT		NEW					
		CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
One Spindle									
Machine Cost/Panel	0	9	45	411	383	318	337	276	276
Labor Cost/Panel	3,958	936	541	998	883	605	522	375	386
Total Cost/Panel	3,958	945	586	1,409	1,266	923	859	651	662
Machine Cost/5,376 Panels	0	51K	242K	2,210K	2,060K	1,710K	1,810K	1,485K	1,485K
Labor Cost/5,376 Panels	21,278K	5,031K	2,908K	5, 65K	4,747K	3,252K	2,806K	2,016K	2,075K
Total Cost/5,376 Panels	21,278K	5,082K	3,150K	7,575K	6,807K	4,962K	4,616K	3,501K	3,560K

Table F-2. Combined Machine Investment Plus Labor Cost ($) Per Panel and Per 5,376 Panels

One Panel Length Table - Two Spindles

	MACHINE TOOL CONFIGURATIONS								
		RETROFIT		NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Two Spindle									
Machine Cost/Panel	-	19	76	467	411	346	402	323	323
Labor Cost/Panel	-	558	361	589	531	393	351	278	283
Total Cost/Panel	-	577	437	1,056	942	739	753	879	606
Machine Cost/5,376 Panels	-	102K	411K	2,511K	2,211K	1,861K	2,161K	1,736K	1,736K
Labor Cost/5,376 Panels	-	3,000K	1,941K	3,166K	2,855K	2,113K	1,887K	1,495K	1,521K
Total Cost/5,376 Panels	-	3,102K	2,352K	5,677K	5,066K	3,974K	4,048K	3,231K	3,257K

Table F-3. Combined Machine Investment Plus Labor Cost ($)
Per Panel and Per 5,376 Panels

One Panel Length Table - Four Spindles

	MACHINE TOOL CONFIGURATIONS								
		RETROFIT		NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5½" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Four Spindle									
Machine Cost/Panel	-	-	-	669	539	539	558	483	483
Labor Cost/Panel	-	-	-	344	313	252	225	184	186
Total Cost/Panel	-	-	-	1,013	852	791	783	667	669
Machine Cost/5,376 Panels	-	-	-	3,599K	2,899K	2,899K	2,999K	2,599K	2,559K
Labor Cost/5,376 Panels	-	-	-	1,849K	1,683K	1,355K	1,209K	989K	1,000K
Total Cost/5,376 Panels	-	-	-	5,448K	4,582K	4,254K	4,208K	3,588K	3,599K

Table F-4. Combined Machine Investment Plus Labor Cost ($)
Per Panel and Per 5,376 Panels

Two Panel Length Table - One Spindle

	MACHINE TOOL CONFIGURATIONS							
	PRESENT	RETROFIT		NEW				
		CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
One Spindle									
Machine Cost/Panel	-	-	-	492	464	380	399	306	306
Labor Cost/Panel	-	-	-	818	703	425	342	195	206
Total Cost/Panel	-	-	-	1,310	1,167	1,972	741	501	512
Machine Cost/5,376 Panels	-	-	-	2,645K	2,495K	2,045K	2,145K	1,645K	1,645K
Labor Cost/5,376 Panels	-	-	-	4,398K	3,779K	2,285K	1,839K	1,048K	1,107K
Total Cost/5,376 Panels	-	-	-	7,043K	6,274K	4,330K	3,984K	2,693K	2,752K

Table F-5. Combined Machine Investment Plus Labor Cost ($)
Per Panel and Per 5,376 Panels

Two Panel Length Table - Two Spindles

(XXX) Values not limited by load/unload times

	MACHINE TOOL CONFIGURATIONS								
	PRESENT	RETROFIT		NEW					
		CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5¼" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Two Spindle									
Machine Cost/Panel	-	-	-	548	493	409	465	353	353
Labor Cost/Panel	-	-	-	409	351	213	180	180	180
							(171)	(98)	(103)
Total Cost/Panel	-	-	-	957	844	622	645	533	533
							(636)	(451)	(456)
Machine Cost/5,376 Panels	-	-	-	2,948K	2,648K	2,198K	2,498K	1,898K	1,898K
Labor Cost/5,376 Panels	-	-	-	2,199K	1,887K	1,145K	968K	968K	968K
							(919K)	(527K)	(554K)
Total Cost/5,376 Panels	-	-	-	5,147K	4,535K	3,343K	3,466K	2,866K	2,866K
							(3,417K)	(2,425K)	(2,452K)

Table F-6. Combined Maching Investment Plus Labor Cost ($)
Per Panel and Per 5,376 Panels

Two Panel Length Table - Four Spindles

(XXX) Values not limited by load/ unload times

	MACHINE TOOL CONFIGURATIONS								
		RETROFIT		NEW					
	PRESENT	CONV.	HSM	CONVENTIONAL		HIGH SPEED MACHINING (HSM)			
	Existing 20 hp 3600 rpm	Existing 100 hp 3600 rpm	Existing 100 hp 12000 rpm	Horiz. for Rough Vert. for Finish 100&150 hp 3600 rpm	Vertical Spindle 150 hp 3600 rpm	Vertical Spindle 75 hp 9000 rpm	Vertical Spindle 100 hp 12000 rpm	Vertical Spindle 150 hp 24000 rpm	Vertical Spindle 150 hp 24000 rpm
Cutters→ PARAMETERS	5½" Rough & Finish	9" Rough & Finish	9" Rough & Finish	14" Rough 9" Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	9" Rough & Finish	2" Rough 9" Finish
Four Spindle									
Machine Cost/Panel	-	-	-	782	652	652	671	541	541
Labor Cost/Panel	-	-	-	209	178	135	135	135	135
						(117)	(90)	(49)	(51)
Total Cost/Panel	-	-	-	991	830	787	806	676	676 !
						(769)	(761)	(590)	(592)
Machine Cost/5,376 Panels	-	-	-	4,207K	3,507K	3,507K	3,607K	2,907K	2,907K
Labor Cost/5,376 Panels	-	-	-	1,124K	957K	726K	726K	726K	726K
						(629K)	(484K)	(263K)	(274K)
Total Cost/5,376 Panels	-	-	-	5,331K	4,464K	4,233K	4,333K	3,633K	3,633K
						(4,136K)	(4,091K)	(3,170K)	(3,181K)